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ABSTRACT

This project was designed to investigate the potential of classroom communication systems (CCSs) for facilitating effective teaching and creating effective learning environments. The study was specifically designed to examine the extent to which teachers use CCSs in their classrooms to facilitate environments which are learner-centered, knowledge-centered, assessment-centered, and community-centered and whether such a result might be possible after only a typical brief teacher inservice summer training program. The specific CCSs used for this study were prototypes of the TI-Navigator, the teacher's computer, and the internet. Selected mathematics and science teachers were trained in effective pedagogical techniques for using the technology and integrating it into their classrooms. Thirty-four teachers attended a week long-workshop at the Ohio State University in August 2001. Ten teachers used the techniques in their classrooms during spring semester in 2002. Toward the end of the semester, researchers associated with this project visited these classrooms as part of a comprehensive assessment effort that included surveys of all students and teachers, select student focus groups, and teacher interviews. It was observed that the use of CCSs in classrooms by teachers tended to facilitate educational environments which were learner-, knowledge-, assessment-, and community-centered. (SOE)

FINAL REPORT

(Part 2 – Technical Report & Research Description)

to the
National Science Foundation

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DEVELOPING PEDAGOGY FOR WIRELESS CALCULATOR NETWORKS -
and Researching Teacher Professional Development

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Dedication

It is our honor to dedicate this work to all the teachers with whom we have worked over the years - especially those who have extended our idea of, "what might be possible," and inspired us to reach for it.

SUMMARY

A small exploratory research project attempted to answer some big questions. The project was designed to investigate the potential of Classroom Communication Systems (CCSs) in facilitating effective teaching and in creating effective learning environments. Drawing on the work of the NRC Committee on the Science of Learning (Bransford, Brown, and Cocking, "How People Learn (HPL) - 1999), the study was specifically designed to examine the extent to which teachers use CCSs in their classrooms to facilitate environments which are learner-centered, knowledge-centered, assessment-centered, and community-centered. Also, whether such a result might be possible after only a typically brief teacher inservice summer training program.

The specific CCSs used for this study were prototypes of the TI-Navigator, which linked student handhelds wirelessly to a classroom server, the teacher's computer, and the internet. The TI-Navigator offered two big advantages over prior, more simple, CCSs. First, it employed commonly used graphing calculators as student handhelds. Thus teachers and students were already familiar with their use, and how to integrate their un-networked versions into a classroom. Second, it was programmable. That is, all functions of the system could be relatively easily invoked by individual application programs targeted at specific curricular or pedagogical needs. However, the systems *were* prototypes, and did suffer from shortcomings commonly associated with technology at this stage of development.

The first step in the project was to train selected mathematics and science teachers in effective pedagogical techniques for using the technology and integrating it into their classrooms. To this end, thirty four teachers attended a week long-workshop, at The Ohio State University in August 2001. The model that we used to develop this special Professional Development Institute was based on the lessons learned in the Teachers Teaching with Technology (T^3) professional development program that was founded at Ohio State University with NSF support in 1988. Pilot teachers presented activities to the workshop participants, who played the role of students. Participants could direct their questions to teachers who were experienced with the technology and model the methods they employed in their own classes using the TI-Navigator System.

When TI subsequently delayed commercial introduction of Navigator because of technical problems, this project was in danger of foundering. However, one semester later than planned, a total of ten teachers received access to systems (8 systems, two shared), and used them in their classrooms during the Spring Semester 2002. Toward the end of this semester, researchers associated with this project visited these classrooms as part of a comprehensive assessment effort, which included surveys of all students and teachers, and select student focus-group and teacher interviews. The results of this work are presented in the report, together with a description of the workshop, and the rationale for the assessment procedures.

We show why we tentatively conclude that we obtained a positive answer to the original research question: namely, that the four HPL centerednesses do increase in classrooms of all ten teachers involved in this study. We also describe in detail, the techniques that we used, and the results that we obtained, to come to this conclusion. In this regard, we also suggest that we have successfully developed what is perhaps the first systematic approach for assessing changes in the HPL centerednesses in classrooms. Finally, we describe our search to explain the underlying processes and mechanisms that produce these effects in classrooms. As a result, in what are perhaps the most interesting and consequential results of this study, we show probable links with several theories related to human motivation, including coping theory, Mazlow's hierarchy of needs, self-worth theory, attribution theory, and self-efficacy theory.

Clearly, the small size of the study was not commensurate with the production of a fully definitive answer to the main question, let alone all its derivatives. However, we feel that we have succeeded in showing a path with significant likelihood for fruitful future research and development.

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GLOSSARY OF TERMS

Assessment Centeredness – Descriptor of an effective learning environment that was first defined in the book "How People Learn"

CCS – A Classroom Communication System

Centerednesses – Four parameters from HPL that describe an effective learning environment

Classroom Communication System – A networked classroom that contains special software to allow it to function as an integrated tool for transmission, management, analysis, and presentation of information related to student tasks.

Classroom Network – A local area computer network that operates within the confines of a classroom

Classtalk – One of the first CCSs that was developed with NSF grant support about a decade ago.

Community Centeredness - Descriptor of an effective learning environment that was first defined in the book "How People Learn"

Cronbach's Alpha – A statistical parameter commonly used to assess the existence of unidimensional latent constructs in survey data

"Experienced" Teachers – Used in this report to refer to teachers with more than two years experience in use of CCS technology in their classrooms

HPL – A book titled "How People Learn" authored by the National Research Council Committee on the Science of Learning and published in 1998

Institute – An in-service training course for teachers common in the T-Cubed Organization

Knowledge Centeredness - Descriptor of an effective learning environment that was first defined in the book "How People Learn"

Learner Centeredness – Descriptor of an effective learning environment that was first defined in the book "How People Learn"

Medusa – Internal name of an early experimental CCS made by Texas Instruments

Naturalistic Research Method - Research methods aimed at producing naturalistic data

Navigator – A prototype CCS made by Texas Instruments and used in this project

Network – Means a computer network, unless otherwise qualified

"New" Teachers – In this report the term refers to teachers who have had three months (or less) experience using a CCS in their classrooms, who formed the "Test-group" teachers.

Positivistic Research Method – Research methods aimed at producing positivistic data.

Private information space in a classroom – student personal information, that is prevented from being made public, except through the express actions of the teacher, or the student to whom it pertains.

Public information space in a classroom – information that is shared publicly for everyone in the classroom.

Response System – A simple form of CCS where "tasks" are limited to multiple choice questions.

Summer Institute – An in-service training course held during the Summer school vacations for teachers, common in the T-Cubed Organization

T- Cubed – "Teachers Teaching with Technology" - An organization to train teachers in the effective use of technology in classrooms, founded by Professors Frank Demana and Bert Waits at the Ohio State University in the late 1980s.

"Test-Group" Teachers – Refers to the ten teacher who attended the Summer Institute at The Ohio State University, under this project and who subsequently received and used TI-Navigator systems in their classrooms during the Spring Semester, 2002

TI – Texas Instruments Incorporated

TI-Navigator – A prototype CCS made by Texas Instruments and used in this project

Wireless network – An electronic computer network that permits wireless communication.

1. INTRODUCTION

1.1 Objectives and Initial Research Plan

This project was designed to investigate the potential of Classroom Communication Systems (CCSs) in facilitating effective teaching and in creating effective learning environments. Drawing on the work of the Bransford, Brown, and Cocking (1999), the study was specifically designed to examine the extent to which teachers use CCSs in their classrooms to facilitate environments which are learner-centered, knowledge-centered, assessment-centered, and community-centered.

The first step in the project was to train (an originally targeted number of) twenty five selected mathematics and science teachers in effective pedagogical techniques for using the new TI-Navigator System. Texas Instruments had agreed to donate twenty five complete systems to these selected teachers free of charge. A longer term goal of this project was to create a cadre of expert users who have experience in employing informed pedagogical techniques which had been shown to be successful in prior NSF-funded research and can relay that experience to others in their field.

There was also an important question to be answered concerning teacher professional development. Namely,

> *"To what degree would it be feasible, given the constraints of a typical in-service teacher enhancement program, to train high school mathematics teachers to use a CCS effectively and make their teaching become more learner centered, knowledge centered, assessment centered, and community centered?"*

Subsequent to the Workshop, follow-up observation visits would be made to the classrooms of all teachers who attended the Workshop. The objectives of these visits were to assess the learner centeredness, knowledge centeredness, assessment centeredness, and community centeredness of these classrooms. The procedures to be used for these assessments were expected to include interviews with teachers, classroom observation (including videotape), and student interviews and written questionnaires. Since this research was exploratory in nature, no attempt was expected to be made to use independent evaluators or to compare with control groups.

1.2 Background

More than two decades of research and experience supports the idea that computer and calculator technologies can have an important role to play in supporting and effecting student learning (Heid, 1988; Kaput, 1992; Kutzler, 1996; Papert, 1980; Waits and Demana, 1999). The development of Classroom Communication Systems (CCSs) is providing new possibilities for technologies to play a fundamental role in creating and supporting effective learning environments. The TI-Navigator, from Texas Instruments, is a wireless CCS and its advent brings the power and potential of CCSs into K-12 classrooms in a novel, flexible and mobile way. The pedagogical potential of CCS technology is still in its development stage but preliminary research suggests considerable benefits to active student participation in class and collaborative inquiry in the classroom (Abrahamson, Davidian & Lippai, 2000; Bransford, Brophy, & Williams, 2000; Davis, 2002; Dufresne, Gerace, Leonard, Mestre, & Wenk, 1996; Mestre, Gerace, Dufresne, & Leonard, 1997; Wenk, Dufresne, Gerace, Leonard, & Mestre, 1997). The present study is designed to illustrate the potential of CCSs in facilitating effective teaching and in creating effective learning environments.

1.3 Theoretical Framework

Bransford, Brown and Cocking (1999) developed a framework for designing effective learning environments. The design of such environments is based on three principles:

- Students come to the classroom with preconceptions about how the world works. If their initial understanding is not engaged, they may fail to grasp the new concepts and information that are taught, or they may learn them for the purposes of a test but revert to their preconceptions outside the classroom.
- To develop competence in an area of inquiry, students must:
  (a) have a deep foundation of factual knowledge,
  (b) understand facts and ideas in the context of a conceptual framework, and
  (c) organize knowledge in ways that facilitate retrieval and application.
- A 'metacognitive' approach to instruction can help students learn to take control of their own learning by defining learning goals and monitoring their progress in achieving them. (pp.14-18)

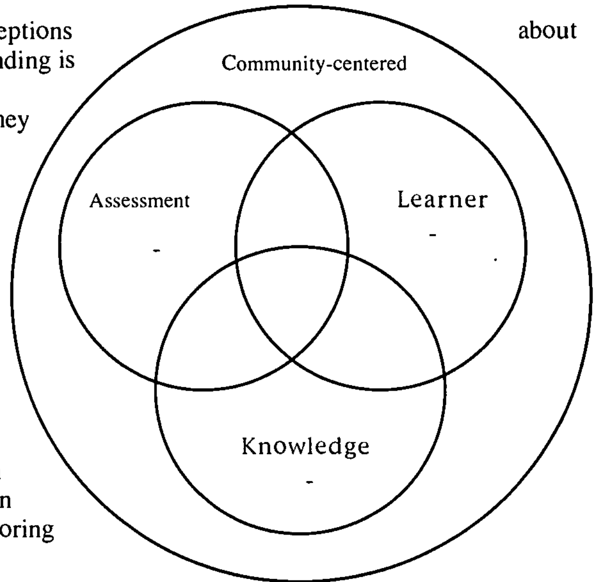


Figure 1. Depiction of the Four HPL Centerednesses as Overlapping Circles

These principles form the basis for a model of learning with specific implications for teaching, called How People Learn (HPL). Consequent to these principles Bransford, Brown and Cocking (1999) propose that effective learning environments should be learner-centered, knowledge-centered, assessment-centered, and community-centered. HPL depicts these constructs as overlapping circles (Figure 1).

Aspects of a teacher taking a learner-centered approach include the extent to which the teacher uses questions, tasks, and activities to show existing conceptions that students bring to the classroom, and the extent to which teachers exert an appropriate amount of pressure on students to think through issues, establish positions, and commit to positions. A knowledge-centered approach manifests itself in a focus on conceptual understanding, and the diagnosis and remedy of misconceptions. Assessment-centered instruction concentrates on formative assessment to provide feedback to students and to teachers on student conceptions. Finally, a community-centered approach is reflected in, for example, class discussion, peer interaction, and non-confrontational competition. (Bransford, Brown & Cocking 1999)

1.4 Potential Significance

The potential significance of this project was to demonstrate the effects of wireless calculator CCSs combined with teacher professional development consisting of a weeklong Summer Institute. We expected that teachers would easily be able to see the potential of this technology for applications such as automated drill and practice. However, our goals for the project were much larger. We wanted to see if teachers, after attending the Institute, would then be able to apply successful research based pedagogies to transform the dynamics of their classrooms, encourage students to actively experience mathematics and science, and teach with the promise of leaving fewer students behind. The way by which these potential results would be assessed was by measuring the HPL centerednesses in the classrooms of teachers who attended the Institute.

2. DESCRIPTION OF THE TECHNOLOGY

2.1 History

From the late-eighties to the present day Classroom Communication Systems (CCSs) have been a slowly evolving technology. This genre of classroom tools originated with simple hard wired multiple-choice "response' systems, but is now being transformed by sophisticated high speed wireless networks, palm-type devices or graphing calculators, and programmable control by a central computer. Along with this transformation comes an almost unimaginable increase in capability, many of whose uses are yet to be completely fathomed.

2.2 Role

Preliminary results suggest that the role that CCS technology has to play in the design of an effective learning environment, centers on the free flow of information in the classroom in that CCS technology gives teachers more information on what students are thinking, gives students more information on what other students are thinking, gives students more information on their progress, and supports sharing of information to facilitate collaborative learning.

2.3 Components and Operation

Modern CCSs consist of five main parts: (a) a computer which is operated by a teacher at the front of a classroom and which runs a software package and displays information private to the teacher; (b) an LCD panel, television, or other type of projection system which displays public information; (c) student devices which may be calculators, computers, palm pilots or organizers; (d) a network which connects student devices to the teacher's computer, interprets communication protocols, and sends tasks to and from students and the teacher; and, (e) software which allows the whole system to function as an integrated classroom tool. Using a CCS, students can for example send answers to multiple choice questions, send alpha-numeric answers to questions, and send lists of numbers based on measurements. The TI-Navigator is a modern CCS which possesses the unique characteristic of being almost totally programmable. That is, a Navigator "activity" may be designed to accept teacher-authored questions or other specific curricular materials, and also whole new activities written by third-party developers or technically sophisticated teachers. For example, in one such activity, students may participate in simulations controlling an on-screen icon, or so-called "turtle."

2.4 Simple Example

The following is an example of how a TI-Navigator activity might work: The teacher sends students a set of multiple choice questions to be answered including the question "What is –3^2?" with possible answers "A. 3; B. 9; C. –9; D. –3; E. 0." Students' progress on the questions can be tracked on the teacher console as they send in their answers. The particular question "What is –3^2?" is a question that many students answer incorrectly due to misunderstanding or misremembering the order of operations necessary to get a correct answer. When all students have sent in answers to the set of questions, the teacher can display histograms of the students' answers. In a class of 25 students the histogram for the question might look as shown in Figure 2.

There are several consequences of using the TI-Navigator worth noting here: (a) every student has had to choose and send in an answer to the question (they cannot just wait for someone else to answer), (b) the teacher knows that almost half of the students have a misconception as to how to simplify this arithmetic expression, (c) students know that probably at least half of them answered "incorrectly," (d) students know that if they were one of those who answered incorrectly they are not alone, (e) misconceptions about how to answer this question have come into the open without any student having

to risk the embarrassment of declaring an incorrect answer (although the teacher knows, from the console, which students answered in which way). Information about the class knowledge state can then be used as a basis for class discussion on the concept of negative numbers and order of operations.

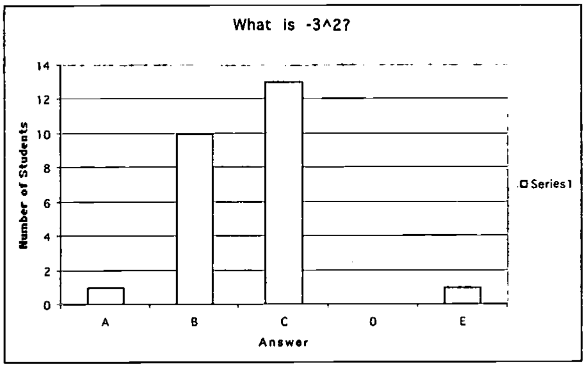


Figure 2. Example of Histogram Shown to Class (from a 5-part M/C Question)

2.5 Advanced Example

Another possibility for using a CCS is participatory simulation such as "Disease" developed as part of the NetLogo project (NetLogo, 2002). The "Disease" model simulates the spread of a disease through a population which consists of on-screen icons (turtles), controlled by individual students via the TI-Navigator network using the arrow buttons on their calculator. Turtles move around a space represented on screen by a grid of patches, possibly catching an infection, with a probability determined by the teacher. Sick turtles make patches they land on infectious for a time during which healthy turtles on the patch have a certain chance of becoming ill. A plot shows the number of infected turtles over time, and there is the option of sick turtles flashing to show that they are infected or keeping turtles' state of health hidden from public view. No matter how the various parameters (chance of infection, initial number of infected turtles, sickness public or hidden) are changed, the same basic plot shape (a logistics curve) emerges. Among the benefits of this sort of activity are (a) an experiential learning experience for students, (b) a cooperative learning experience for students, (c) a physical and visual connection that students can make to mathematical objects such as graphs.

3. PROJECT DESCRIPTION

3.1 Preparation for the Institute

TI-Navigator Planning Meeting, June 8-10, 2001

The purpose of this meeting was to plan the 5-day Professional Development Institute to be held August 4-9, 2001 at The Ohio State University in Columbus, Ohio. In addition, we planned the research component of the project.

Attending the Meeting:
PIs: Doug Owens, Frank Demana and Louis Abrahamson
MacArthur High School Teachers, New York: Andy Lippai and Ann Davidian
Franklin Heights High School Teachers, Ohio: Jim Kozman and Doug Roberts
Graduate Research Assistants: Marlena Herman and Michael Meagher

We began with a general discussion of what should be included in this 5-day institute and came up with a list of important concepts that needed to be covered in the institute.

After this list was composed, we broke into two working groups:
Group 1: Demana, Lippai, Davidian, Kozman, and Roberts designed the daily activities for the institute activities.
Group 2: Owens, Abrahamson, Herman and Meagher worked on designing the research project and instruments.

After repeated drafts and revisions, the team left the meeting with their assignments needed to complete the plan.

Training Design

The model that we used to develop the Summer 2001 Professional Development Institute was based on lessons learned in the Teachers Teaching with Technology (T^3) professional development program that was founded at The Ohio State University in 1988 (with NSF support). Today T^3 continues to train teachers in the appropriate use of technology using a cadre of nearly 180 teacher leaders from across the United States. The organization has also spread to twenty three other countries around the globe and has had a major impact on the teaching of mathematics and science (http://www.t3ww.org/). Prof. Frank Demana, the co-founder of T^3 is one of the principal investigators on this grant.

The activities selected for use in the TI-Navigator Workshop were based on standard mathematics and science content topics that were redesigned by several of the initial pilot TI-Navigator teachers to take advantage of the TI-Navigator System. The activities were planned to be presented to the workshop participants, playing the role of students, by the pilot teachers, so that participants could direct their questions to teachers who were able to, "talk the talk because they had walked the walk." The pilot teachers modeled the methods they used in their own classes using the TI-Navigator System.

The plan for each day's activities allowed for debriefing time with the workshop participants. The debrief was to provide participants the opportunity to reflect on the day's activities and make suggestions which were incorporated into the following day's activities. This process helped the workshop participants buy into and take ownership of the approach. This approach has, since its inception, been found to be fundamental to the success of the T^3 Program.

3.2 Holding the Institute

Program

An annotated copy of the week-long program of activities is contained in Appendix 1.

The Task

The task was to train twenty-five middle school and high school teachers in the use of the TI-Navigator system. Aside from technical training in the use of the system, the institute was designed to introduce the teachers to several pedagogical techniques which have been successful in the use of Classroom Communication Systems (CCSs) in general and the TI-Navigator in particular. Among these techniques are the use of polling as a springboard for class discussion, data collection and dissemination, interactive group simulations, and the provision of immediate feedback to students.

3.3 Systems In Place – TI Revises Product Design

Original Plan for TI-Navigator Systems in Classrooms

When this project entered detailed planning during Spring 2001, TI had announced (on February 7, 2001) that the TI Navigator System would begin shipping in late Summer of that year. TI had also signed up about 100 schools under a special program where these sites would receive "Collaboration Grants" from TI for their first systems. These grants would reduce the price of the systems to the participating schools by approximately 50% of the anticipated purchase price. The teachers participating in the NSF SGER sponsored Institute were drawn from these schools who had already been awarded TI Navigator Collaboration Grants. The participants at the Institute comprised 25 teachers from 13 States throughout the continental USA and Hawaii. An additional 8 teachers from Canada whose expenses were paid by TI Canada attended as visitors. One professor of higher education from New York, who intended to help K-12 teachers, was supported by TI.

By the time that the Institute was held in early August 2001, it was becoming clear that TI was having technical difficulties with the Navigator design and that their goal of shipping systems in late Summer was not likely to be met. In a presentation given at the Institute in Columbus by TI representatives they were asked by the teachers when they could expect to receive their systems. The TI representatives replied that they were not able at that point to give a firm date, and that the matter of Navigator design was currently under consideration at TI.

TI Revises Product Design – Delays Schedule

As the year progressed it became apparent that a resolution of the technical difficulties that TI was encountering was unlikely to be quick or simple, and that a total redesign of the Navigator system was going to be necessary. At this point TI would not give a new date for product release, except to say that it could be expected sometime in 2003.

Rescuing the Project – Considerations and Alternatives

A delay of a year or more in the availability of TI-Navigator was potentially disastrous for the research planned under this project. A majority of the funds had already been spent in holding the Institute to prepare teachers for using the systems. If they then did not receive systems, the research could not be completed and the money already spent would be wasted in terms of achieving the proposed research goals of assessing the effectiveness of the institute. The issue of timing was also critical, because the information in the courses taught at the Institute would likely be forgotten if too much time were to elapse before it could be used. In fact, the courses had been planned under the assumption that teachers would be receiving their systems within a month after the end of the Institute in time for the start of the

fall school semester. Now, there was a possibility that three or four whole semesters might elapse before they would receive systems. Clearly, this was an unacceptable option and we struggled to find an alternative plan to rescue the project.

One alternative was to consider using a limited number of prototype Navigator systems for the planned research. In support of this idea was the fact that the prototype systems *had* proved to be usable in classrooms although they were still "buggy." Also, there would be some familiarity with these systems since this was the same system which teachers had used during the institute which they had attended at The Ohio State University in Columbus in August 2001. A negative was that the existing Navigator prototypes required a fast internet connection (T1-line) at each school where it was used. On balance, it was decided that the positives outweighed the negatives and the PIs on this grant decided to attempt to make the project work using prototype equipment.

Actual Systems and Sites Used for This Research

In November 2001, the PIs on this Grant approached Texas Instruments with the request to make a limited number of prototype Navigator systems available to teachers who had attended the August 2001 Institute at Ohio State, for the purpose of this research. TI was initially reluctant to do this because of the known reliability problems with the prototype systems. They were also concerned that the number of systems which we had requested (16) would overload their prototype server in Dallas.

Ultimately, we agreed on ten systems to be deployed at the following sites:

Debbie Kula & Tim Cantley, (Math) Sacred Hearts Academy, Honolulu, Hawaii
Jim Small, (Physics) Shiloh High School, Snellville, Georgia
Diane Hirsch, (Math) Washington High School, Phoenix, Arizona
Corey Boby, (Math) Arkansas School for Mathematics and Science, Hot Springs, Arkansas
Lisa Suarez and Martha Verde, (Math) Luiz Munoz Marin Middle School, Cleveland, Ohio
Valerie Kegeris, (Chemistry) Danville High School, Danville, Illinois
Bud Ellis, (Biology and Chemistry) Addison High School, Addison, Michigan,
Derek Driscoll, Westminster Secondary School, London, Ontario
Mildred Higgins, Gildersleeve Middle School, Newport News, VA
Darwin Mills and Geoffrey Coleman, (Math and Biology/Chemistry) Heritage High School, Newport News, Virginia

These teachers received their systems from TI from January to March 2002. With the exception of the Newport News VA schools (who had a problem with their internet connection at the district level and never used the systems), all teachers were using their systems during the second half of the spring semester 2002.

3.4 Site Visits

We began site visits in Mid-April, 2002. These visits were lasted for a minimum of one full day and in many cases lasted for two days at each site. The members of the research team who visited the different sites are listed below:

Michael Meagher (Diane Hirsch, Martha Verde, and Lisa Suarez)
Louis Abrahamson (Debbie Kula,, Tim Cantley, and Jim Small)
Marlena Herman (Corey Boby)
Doug Owens (Valerie Kegeris, Bud Ellis, and Derek Driscoll)

A typical scenario for the site visits is described below:

Two weeks prior to visit: parental permission forms, blank student surveys, teacher survey, and teacher visit preparatory sheet sent to test site.

Days prior to visit: (1) teacher(s) collect parental permission forms from students,
(2) have students complete student surveys,
(3) complete teacher survey form
(4) complete visit preparatory sheet.

Day before visit: Teacher drops off completed survey forms and permission slips at visiting researcher's hotel.

Night before visit: Researcher collates results and tallies student surveys for each class.

First day of visit: (1) Researcher visits school,
(2) Formally observes class(es) using TI-Navigator
(3) During free period (after school/at lunch) conduct student focus group interview(s) (using the tallied student responses as a basis for interview question),
(4) During free period (after school/at lunch) conduct teacher interview using teacher's response to survey questions).

Second day of visit: If more than one teacher at this school is using TI-Navigator, repeat first day schedule with second teacher.
Or, if only one teacher at school is using Navigator, then schedule is more relaxed and the first day might be used mainly for classroom observation and informal discussions with teacher, or items listed above might be split between both days.

3.5 Data Analysis

Interviews transcribed and reviewed by each researcher.

All survey results tallied and collated and plotted.

June 22, 2002 - Research team (Doug Owens, Frank Demana, Louis Abrahamson, Michael Meagher, and Marlena Herman) mets in Columbus over a two day period to review data and discuss data analysis.

July, August, September, and October – Data analysis, theoretical correlations, and report writing.

4. ASSESSMENT METHODOLOGY

4.1 Goal

The goal of these assessments was to measure how the introduction of TI-Navigator system changed the HPL centerednesses of the test classrooms. However, the centerednesses are complex constructs which have only recently been defined in a combined way and given the coherence appropriate to their foundation in thirty years of cognitive science research (Bransford, Brown, & Cocking,, 1999). To our knowledge, they have never actually before been assessed in classrooms.

The deeper implications of attempting to measure the centeredness constructs in real classrooms was somewhat daunting to this researcher team. Also, since this was a small low-budget project with a focus on exploratory research, there was no opportunity for techniques such as pre/post measurements or the use of control groups. Thus, it is necessary to answer the question of why we would embark on such an ambitious task, and why we believed it was necessary in this context to attempt to synthesize a valid research project around such complex constructs. We try to answer these two questions in the following section.

4.2 Significance of the HPL Centerednesses to the Research

In 1999, the National Research Council (NRC) Committee on Developments in the Science of Learning published its report, edited by Bransford, Brown, and Cocking, (1999) entitled *How People Learn - Brain, Mind, Experience, and School* (HPL). As indicated in the title, the committee used what was known about learning to also consider characteristics of effective learning environments. As an organizing principle in this endeavor they employed the deeply insightful concepts of learner centeredness, knowledge centeredness, assessment centeredness, and community centeredness.

We believe that the definition of these concepts is of enormous importance, because it is our opinion that for the first time in education research, the committee gave form and structure to variables on which a model of effective educational environments can legitimately be thought to depend. Achieving a verified reliable model of effective learning environments would be giant step towards making teaching more scientific. In general, at one extreme a model may comprise a purely empirical expression of trends and dependencies that embodies little or no understanding of mechanisms, extraction of concepts, synthesis of principles, or explanation of relationships. At the other extreme it may be a beautifully elegant reduction of a huge number of situations into a highly compact, coherent, and general form. Because of their solid roots in cognitive science research, it appears likely that the HPL centerednesses have the potential to produce a model closer to the latter than the former.

A verified reliable model of effective learning environments is important for the following reason. Even in the so-called "hard" sciences, researchers tend to view each other's data with healthy skepticism. Especially if results are unexpected, peers question experimental design, assumptions, methodology, and interpretation. There is one exception to this rule. If scientists understand "why" their peers' results are turning out like they are, then the skepticism vanishes. Education is more problematic in this regard than most sciences. It is not only difficult to make measurements, they are also harder to understand.

Also, the objective of much educational research and development tends to be directed at showing "what" works. But, in education "what works" in one situation does not always work in another. So, this makes it even more desirable to understand "why" and "how" things work. Understanding the answers to these two questions allows for communication of a coherent case for change, and reduces ambiguity by facilitating meaningful comparison of different tools, curricula, and techniques.

4.3 "Why aim to measure the HPL Centerednesses for this project?"

It is probably not obvious that there is any connection between CCS technology and breakthroughs in modeling effective educational environments. That is, one may accept the importance of the HPL centerednesses to education research in general, without seeing a compelling reason to use these constructs and invest in pioneering assessment techniques to measure them within the context of a small exploratory research project related to a new technology.

We feel that there are two answers to this question:

1. Experience from prior situations (Defresne et al., 1996; Mazur, 1997; Abrahamson, 1998, 1999, 2000) has shown us that CCS technology has complex effects on the ecology of classrooms and that these effects are not amenable to simple descriptors; and,
2. Review of the centeredness parameters in HPL indicated that these parameters hold promise in explaining effects which had been observed in CCS classrooms;

Our experience in these issues has deep roots. One of the PIs on this project (Louis Abrahamson) began working with a series of early prototypes of CCSs (called Classtalk) in 1987. These primitive systems were found to transform introductory university physics courses from dull passive lectures to lively active happy places (Abrahamson, 1998, 1999, 2000). Subsequent research in student learning showed huge gains in widely different learning environments. For example, at Harvard University conceptual understanding gains in introductory physics courses doubled (Mazur, 1997), and inner-city 5th grade reading comprehension soared (from 54% to 89% pass rate on state Degree of Reading Power (DRP) tests with one-third of the students growing five years from 2nd to 7th grade level) after only four months (Hartline, 1999). Another PI (Frank Demana) began work with predecessors of the TI Navigator in 1998, setting up and monitoring a test site a Franklin Heights High School. A third PI (Doug Owens) and his graduate student Marlena Herman were also involved in work at this school.

But, in struggling to understand and describe what we were seeing we all realized that something was missing. Now, the science of learning has begun to show how to understand these results. See, for example, *How People Learn* (Bransford, Brown, & Cocking,1999; Bransford, Brophy, & Williams, 2000). Thus we envisioned the possibility of a breakthrough, of being able to provide the beginnings of answers to questions that would be critical to all education as we embarked on the use of a truly transformative technology. Questions such as:

- What happens in classrooms when a CCS is introduced?
- How are these effects caused?
- Are the effects beneficial? and if so,
- Why?

... could and should be answered.

4.4 Overview of Research Methods

In choosing a research methodology, we began with a review of educational research methods. Our findings are summarized in the next two paragraphs.

Broadly speaking, there are two possible classes of methods, positivistic and naturalistic. Positivistic methods are most commonly associated with natural science but have received criticism in their application to social sciences for various reasons. In the case of education research however, we feel that the most cogent criticisms against positivism can be stated in two ways. First, from the perspective of a natural scientist the core difficulty in designing reliable educational experiments is control of variables. In education, the number and importance of variables that usually cannot be controlled are sufficiently large that results can be suspect, no matter how careful the experimental design or how big the population. An alternative more philosophical point of view, might say that the mechanistic and

reductionist perspective of positivistic natural science tends to exclude individual subjectivity when applied to social science. But, this subjectivity is critical to understanding the relationship between events and human behavior. Thus, "the findings of positivistic social science are often said to be so banal and trivial that they are of little consequence to those for whom they are intended, namely, teachers, social workers, counselors, and the like. ... [Thus,] the more effort researchers put into [positivistic] scientific experimentation by simplifying and controlling variables, the more likely they are to end up with a 'pruned, synthetic version of the whole, a constructed play of puppets in a restricted environment,' (Menzel, 1978)" (Cohen, Manion, & Morrison, 2000, p. 17).

The alternative to positivist approaches in the social sciences emphasizes naturalistic, qualitative, and interpretative inquiry where the observers are recognized as being non-detached and not objective. Therefore a description of the observers must necessarily be included with the observations. Additional viewpoints behind the various schools of naturalistic inquiry can be strongly anti-positivist. For example, that people are not "passive dolls" (Becker 1970, Garfinkel 1967), that reality is multi-layered, complex, and never reducible to simplistic generalizable interpretation. Other less extreme viewpoints emphasize that people are deliberate and creative, and that it is necessary to examine situations through the eyes of participants as well as the researcher.

4.5 Choice of Methods

It will be apparent to the reader that our assessment goals in this project were very ambitious. Learner centeredness, knowledge centeredness, assessment centeredness, and community centeredness are ideas which are enormously powerful but have never before been considered as "parameters" which could be measured and used to describe a particular educational environment.

From our review of research methods we concluded that neither positivistic nor naturalistic approaches alone, were going to be adequate for our purposes. We concluded that the best possible approach would be to attempt to use both methods, in a combined way. But, it also had to be easy to do. We tried various approaches in pilot classrooms. Two researchers on the team also attended a special short course held at MIT on the VOS (VaNTH Observation System, 2000) which is being developed specially for classroom observation from the HPL centeredness perspective at Vanderbilt University.

Ultimately, we developed the set of survey instruments described in the following sections which we felt would give us a reasonable chance of accomplishing our goal.

4.6 Survey Instruments

Copies of the Survey Instruments developed for this study are contained in Appendix 2. They consist of:

a) Initial Teacher questionnaire
b) Pre-visit questionnaire
c) Student Survey
d) Teacher Survey
e) Classroom Observation
f) Student Focus-Group Interviews
g) Teacher Interview
h) Final Teacher Questionnaire

These instruments were designed to be used in the following process.

4.7 Process

The participants in this study are ten high school mathematics and science teachers and their students. The teachers are experienced in teaching with graphics display calculator technology and were trained in the technical aspects of operating the TI-Navigator system as well as pedagogical techniques and possibilities available in a networked classroom. Before the training, teachers were surveyed in open question format (Initial Teacher Questionnaire, Instrument (a), Appendix 2) about their pedagogical practices and then surveyed again at the end of the school year (Final Teacher questionnaire, Instrument (h), Appendix 2) about possible changes in their practice. A series of visits was undertaken to their classrooms where the TI-Navigator system is being used.

Shortly before the visits to classrooms, teachers and students completed Likert-style surveys (Instruments (c) and (d), Appendix 2) specifically designed to elicit their views on topics relating the extent to which TI-Navigator classrooms reflect the HPL model; that is, the extent to which TI-Navigator classrooms are learner-centered, knowledge-centered, assessment-centered and community-centered. During the visits, formal observations of classes were made using the VaNTH Observation System (VOS) (Harris & Brophy, 2002). This system is designed to capture classroom interactions reflecting the HPL model. Interactions in the classroom are recorded and categorized as examples of one of the centerednesses. Responses to the Likert-style surveys were used as the basis of protocols for focus group interviews with students and individual teacher interviews (Instruments (f) and (g), Appendix 2). Therefore, the interview protocols were designed to gain further insight into the TI-Navigator classroom as exemplification of HPL effective learning environments.

4.8 Student and Teacher Survey Items and HPL Centeredness

The Likert Scale student and teacher surveys (Instruments (c) and (d), Appendix 2) were designed with two statements representing key attributes of each centeredness. Each statement was then also expressed in a negative sense, to give a total of four statements for each centeredness, which were then written in randomized order. Thus, for the student survey:

Learner Centeredness

L^1 (15)	Doing activities in class with the TI-Navigator helps me relate new material to things I already know	SD	D	N	A	SA
L^{-1} (8)	I find no advantage in using the TI-Navigator to help me build on my knowledge	SD	D	N	A	SA
L^2 (6)	I am more actively engaged in a TI-Navigator class than in others	SD	D	N	A	SA
L^{-2} (10)	I am equally on task in TI-Navigator classes and other classes	SD	D	N	A	SA

Where, L^1 & L^{-1} relate to "transfer," and L^2 & L^{-2} "active engagement," two key aspects of learner centeredness. (Note: actual order is in parentheses.) Similarly for knowledge centeredness, items K^1 & K^{-1} relate to aiding "understanding of concepts," K^2 & K^{-2} to "increased effort"; for assessment centeredness A^1 & A^{-1} reflect "feedback to students," A^2 & A^{-2} student perceptions of "feedback to the teacher"; for community centeredness C^1 & C^{-1} give "class interaction and dynamics," while C^2 & C^{-2} assess effect on classroom "sense of community"; as follows,

Knowledge Centeredness

K^1 (13)	Doing activities with the TI-Navigator in class helps me get a better understanding of concepts	SD	D	N	A	SA
K^{-1} (1)	Using the TI-Navigator does not help improve my understanding	SD	D	N	A	SA

K^{2} (9)	Some TI-Navigator questions make me try really hard to answer them	SD	D	N	A	SA
K^{-2} (7)	The TI-Navigator makes no difference to my effort in answering questions	SD	D	N	A	SA

<u>Assessment Centeredness</u>

A^{1} (12)	Using the TI-Navigator I can quickly tell whether or not I am right or wrong	SD	D	N	A	SA
A^{-1} (11)	Using the TI-Navigator does not help in letting me know where I stand on a question	SD	D	N	A	SA
A^{2} (5)	The TI-Navigator helps the teacher tell if I understand a concept	SD	D	N	A	SA
A^{-2} (3)	The teacher knows just as much about my understanding without the TI-Navigator as with it	SD	D	N	A	SA

<u>Community Centeredness</u>

C^{1} (14)	Class interactions resulting from using the TI-Navigator help my learning	SD	D	N	A	SA
C^{-1} (2)	Class dynamics are not affected by the use of the TI-Navigator	SD	D	N	A	SA
C^{2} (4)	There is a greater sense of community in a TI-Navigator class than in other classes	SD	D	N	A	SA
C^{-2} (16)	Using the TI-Navigator does not improve the sense of community in classes	SD	D	N	A	SA

4.9 Approach – Key Details

The assessment techniques were an interweaving of positivistic and naturalistic methods. That is, we relied on the results from student surveys and teacher surveys (Instruments (c) and (d) Appendix 2) as a positivistic base to be complemented by the student focus groups and teacher interviews as naturalistic components.

A key detail in this interweaving was accomplished by a simple technique which we found to be very powerful. In the surveys, we asked students to rate statements as in the following example:

For each of the following statements indicate whether you Strongly Disagree (SD), Disagree (D), Neither agree nor disagree (N), Agree (A), or Strongly Agree (SA) by circling the appropriate choice to the right of the statement.

2	Class dynamics are not affected by the use of the TI-Navigator	SD	D	N	A	SA

Then in the student focus groups we asked questions of the following type:

> "One of the survey questions asked you respond to the statement 'Class dynamics are not affected by the use of the TI-Navigator.' Most students said that they disagreed. Why do you think they responded in this way?"

We found that students typically began interviews giving reasons why they thought their fellow students answered in that way, but then freely opened up and gave their own reasons why they had answered in

one way or another. This gave the focus-group interviews a great deal of candor and revealed depths of perception that added structure to the survey instrument responses.

We used a similar approach to link the teacher surveys with the teacher interviews, by asking:

For each of the following statements indicate whether you Strongly Disagree (SD), Disagree (D), Neither agree nor disagree (N), Agree (A), or Strongly Agree (SA) by circling the appropriate choice to the right of the statement.						
1	Using the TI-Navigator does not help improve student understanding	SD	D	N	A	SA

"One of the survey questions asked you respond to the statement 'Using the TI-Navigator does not help improve student understanding.' You responded that you were neutral. Why did you respond in this way?"

We found that the teachers were more than keen to amplify their answers to the survey questions, and this process provided much deeper insights for all the researchers than would have been the case from surveys alone. It also gave the teachers the opportunity to think through the issues being addressed by the question, and the opportunity to decide on their viewpoint before the interviews. None of the interviewees (students or teachers) knew in advance what would be covered in the interviews.

4.10 Survey-Related Specificities of the Theoretical Framework

A reading of *How People Learn* (HPL) reveals a breadth and depth of issues that clearly have not been addressed in the sixteen items on our student and teacher surveys. The key question is, in spite of this admitted shortcoming, whether we have adequately captured the essence of the four centerednesses in these surveys? To address this question we include a brief informal summary of topics raised in HPL (see Appendix 3), and discuss our abstraction of these topics below

Learner Centeredness

According to HPL, "learner-centered" refers to environments that pay careful attention to the knowledge, skills, attitudes, and beliefs that learners bring to the educational setting. This term includes teaching practices that:

- build on the conceptual and cultural knowledge that students bring with them to the classroom by,
    - constructing a bridge between the subject matter and the student;
    - helping students make connections between their previous knowledge and their current academic tasks;
    - identifying students' knowledge, interests, and passions;
    - incorporating students' home and community cultural practices and language use;
    - connecting everyday talk with school talk;
- fit the concept of "diagnostic teaching" by,
    - attempting to discover what students think in relation to the problems on hand;
    - challenging and discussing students' misconceptions sensitively;
    - giving students situations (critical tasks) to go on thinking about which will enable them to readjust their ideas;
    - prompting students to explain and develop their knowledge structures by asking them to make predictions about various situations and explain their reasoning for their predictions;
    - discussing conflicting viewpoints; and,

- have been called "culturally responsive," "culturally appropriate," "culturally compatible," and "culturally relevant."

Items L^1 and L^{-1} in our surveys address the above topics which relate to using and building on prior knowledge (i.e. "transfer"). Our approach in these two survey items is direct. That is, we simply ask students if this happened? However, for other topics we felt it was more appropriate to use an indirect or "outcomes measure." Thus, to assess the degree to which students' interests, passions, community, cultural practices, or everyday experience were invoked, items L^2 and L^{-2} ask students about the degree to which they were "actively engaged" or "on task." These would not only be likely outcomes of connecting with interests and perceived relevance, but active engagement is also fundamental to a constructivist viewpoint of learning. This would be the antithesis of passive listening, note-copying, or other mentally relatively-disengaged activities.

Our learner-centered survey items do not directly address the issues of diagnostic teaching, because these overlap with knowledge centeredness and assessment centeredness. Also the issue of discussing misconceptions sensitively, and other related classroom discourse issues are closer in our conception to community centeredness.

Knowledge Centeredness

HPL terms teaching practices in knowledge-centered environments, as those which:

- take seriously the need to help students become knowledgeable by learning in ways that lead to understanding;
- focus on the kinds of information and activities that help students develop an understanding by,
    - critically examining existing curricula;
    - considering depth vs. breadth of content covered;
- include an emphasis on sense-making—on helping students become meta-cognitive by expecting new information to make sense and asking for clarification when it doesn't;
- fit the concept of "progressive formalization" by,
    - beginning with informal ideas that students bring to school and gradually help them see how these ideas can be transformed and formalized;
    - moving from students' own words to standard conventional language and notation after they have had sufficient experience with underlying concepts;
    - questioning what is developmentally appropriate to teach at various ages;
- foster an integrated understanding or overall picture of the discipline (e.g. mathematics) instead of skills in isolated pieces by,
    - structuring activities so that students are able to explore, explain, extend, and evaluate their progress;
    - striking the appropriate balance between activities designed to promote understanding and those designed to promote the automaticity of skills necessary to function effectively.

Student and teacher survey items K^1 and K^{-1} directly address the issue of gaining conceptual understanding which is central to many of the above points. So, it is not necessary to explain these two items any further.

However, the reader may not easily be able to discern the connection between survey items K^2 and K^{-2} and the HPL topics listed above. Both these survey items relate to the issue of TI-Navigator tasks "making" students "try harder" or exert more "effort." But, the issue of effort is not mentioned in any of

the above topics. In designing these survey items our group began with two candidate items which included the words,

"Some TI-Navigator activities made me try really hard to make sense of the subject matter," and,

"I do more thinking in classes where the teacher lectures, than I do when we use TI-Navigator."

But, the argument was made that while both of these two items were perhaps more specific in a cognitive science sense, that neither was as meaningful to students as a simple direct statement regarding effort. Also, it was felt that, a simple direct measure regarding effort would be more relevant to this research in terms of students trying to make sense of the content.

Assessment Centeredness

The key principles of assessment are that they should provide opportunities for feedback and revision and that what is assessed must be congruent with one's learning goals.

HPL lists teaching practices in assessment-centered environments as those which:

- utilize both formative and summative assessment,
    - formative—sources of feedback to improve teaching and learning (ex: informal comments on work in progress);
    - summative—measures of what students have learned at the end of some set of learning activities (ex: unit exams);
- focus on understanding, not just memory for procedures or facts;
- provide continuous, yet not intrusive, feedback as part of instruction;
- monitor both group work and individual performances;
- help students build skills of self-assessment and peer-assessment;
- provide students with opportunities to use assessments to revise their thinking;
- help teachers rethink their teaching practices.

Our survey items focus exclusively on formative assessment, because we feel that this issue is the one most relevant to improving educational environments, and also the one that is most difficult to do well. Items A^1 and A^{-1} address feedback to students, items A^2 and A^{-2} address feedback to the teacher. Two items ask about perception of a student's understanding or lack thereof, with reference to specific knowledge components. The other two focus on the existence of feedback regarding critical issues.

Community Centeredness

In HPL, "Community centered" refers to several aspects of community, including the classroom as a community, the school as a community, and the degree to which students, teachers, and administrators feel connected to the larger community of homes, businesses, states, the nation, and even the world.

In community-centered classrooms and schools, learning is enhanced by social norms that,

- value the search for understanding;
- value high standards for learning;
- allow students and teachers the freedom to make mistakes in order to learn;
- do not hinder students' willingness to ask questions when they do not understand the material;
- explore new questions or hypotheses;
- convey expectations for school success for all students;
- are sensitive to modes of participation and levels of competition that may be unfamiliar to students;
- connects what is learned in school to out-of-school learning and vice versa.

It was the feeling of our research group that HPL's description of community centeredness as reflected in above topics was in some ways too explicit, for easy adaptation to survey items. Our conception of what classrooms could be in this regard was better reflected in the simpler more general words, "sense of community." It also included a number of characteristics (see Appendix 3) which had been observed (Abrahamson, unpublished) in prior CCS classrooms, and which appeared to dramatically aid in building the sense of community within the classroom itself. We had also observed that CCS classrooms appeared to possess a dynamic that was radically different to other classrooms, and that the effect of this was to convey changes in relationships and interactions between the students themselves, and between them and the teacher. Thus, we also wanted to include the words "dynamic" and "interactions" in our survey items.

Student and teacher survey items C^1 and C^{-1} directly address the latter issue of changed interactions and dynamic, and C^1 specifically links the interactions to the clause "helped my learning." Items C^2 and C^{-2} both focus on "sense of community" but C^2 compares this class to other classes, and C^{-2} talks about "improving" it in the same class. In spite of the general terminology used in items C^1 through C^{-2}, it was found that students' interpretations of outcomes were almost an exact match to the list of topics from HPL listed above. (See Section 8 below.)

5. RESULTS FROM TEST CLASSROOMS

5.1 Overview

A overview of the research process is shown in Figure 3. It begins with the original objective of the project which was to provide an answer to the following research question:

> *"Does use of CCSs in classrooms by teachers (following a teacher training Summer Institute) tend to facilitate educational environments which are learner, knowledge, assessment, and community centered?"*

Because the concepts of the four centerednesses from the book "How People Learn" were intrinsic to the research question, it was obvious that they should form the central core of theory to inform the research design. The other main input to the design of the research project was a considered review of educational research methods, which caused us to choose a combination of positivistic and naturalistic methods of assessment as described in the previous section.

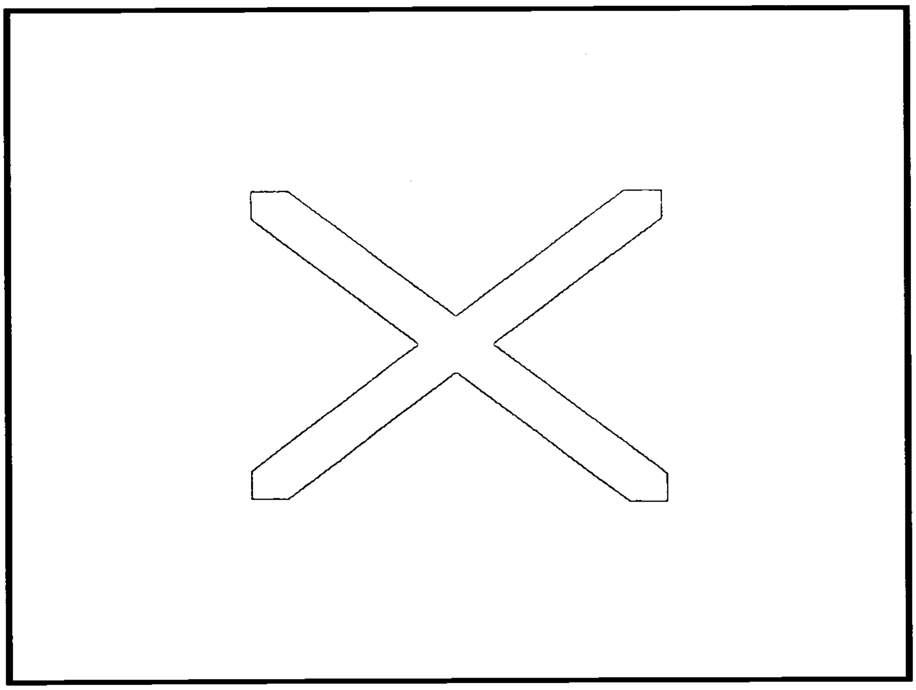


Figure 3. Graphical Summary of Research Process

In this section we describe the results of this research. Briefly, the main conclusion was a positive answer to the research question. However, the data which we obtained also provided material for investigating the answers to questions, such as, "How?" and "Why?" these effects are caused. Our attempt to provide an analysis of underlying mechanisms is contained in a subsequent section (Section 8).

5.2 Teachers & Classes

The data analysis in this paper focuses on ten teachers in twenty four classes (as listed in Table 1), ranging from 8th Grade to 12th Grade, who used the TI-Navigator during the Spring Semester 2002, and who also attended the Summer Institute in Columbus during August 2001. For comparison purposes we will also refer to data from three teachers (as listed in Table 2) who served as instructors at the

Summer Institute and who have had several years of experience with TI-Navigator, its' prototypes, and also (in one case) another CCS.

TABLE 1 - List of Teachers and Classes Used for the Research

TEACHER	Classes	Subject	Grade	#Students	#Times Used Navigator	System Problems	School
Kula	Calculus 3 Geometry 7 Geometry 6 Precalculus 5	Math " " "	12 9-11 9-11 10-12	10 16 25 20	a a a b	Medium	Private (HI) Urban (all girls)
Cantley	Precalculus 2 Precalculus 5	Math "	10-12 10-12	25 19	a a	Severe	Private (HI) Urb(all girls)
Small	Block 3 Block 4	Physics "	10-12 10-12	23 22	a b	Medium	Public (GA) (surburban)
Ellis	Period 2 Period 3	Chemistry "	9-11	8 17	a a	Medium	Public (MI) Rural
Suarez		Math	8		b	Medium	Public (OH) (Hisp.Pop)
Verde		Soc.Stud.	8		b	Medium	Public (OH) (Hisp.Pop)
Driscoll	Precalculus 1 Discrete M 3	Math "	10-12 10-12	20 18	c c	Low	Public (Ont) Urban
Kegeris	Period 2 Period 3	Chemistry "	9-11	13 12	a a	Medium	Public (IL)
Boby	Period 3 Period 5 Period 6	Math " "	9-12	17 10 19	a a a	Medium	Public (AR) Regional (St. Magnet)
Hirsch	Period 2 Period 3 Period 5 Period 6 Period 7	Math " " " "	9-12	19 18 22 18 18	a a a a a	Severe	Public (AZ) Urban

(Approx. Times Used Navigator in this class: a <10, 10<b<20, c>20)

TABLE 2 – Experienced Teachers (2-4 yrs also Institute Instructors) and Classes Used for Comparison

TEACHER	Classes	Subject	Grade	#Students	#Times Used TI-Navigator	System Probs.	School
Davidian	PreCalcHon1 AP Calc 5 AP Calc 6	Math " "	10-11 11-12 11-12	16 18 14	All year " "	Low	Pub (NY) Urb. (Blue collar)
Kozman	AP Calculus	Math	11-12	14	All year	Low	Pub (OH) Sub.(BC)
Roberts	Algebra "	Math "	9-11	14 14	All year	Low	Pub (OH) Sub.(BC)

5.3 Student Surveys

The student surveys were constructed from eight pairs of confirming and disconfirming statements designed to reflect aspects of each of the four centerednesses. The results, reported below (see Figure 4), show broadly, that most students responded positively (agreed or strongly agreed) to statements about the extent to which working with the TI-Navigator enabled particular constructs related to the HPL centerednesses. These results are based surveys of all twenty-two classes from eight of the teachers listed in Table 1, but omit the data from the Cleveland site[1].

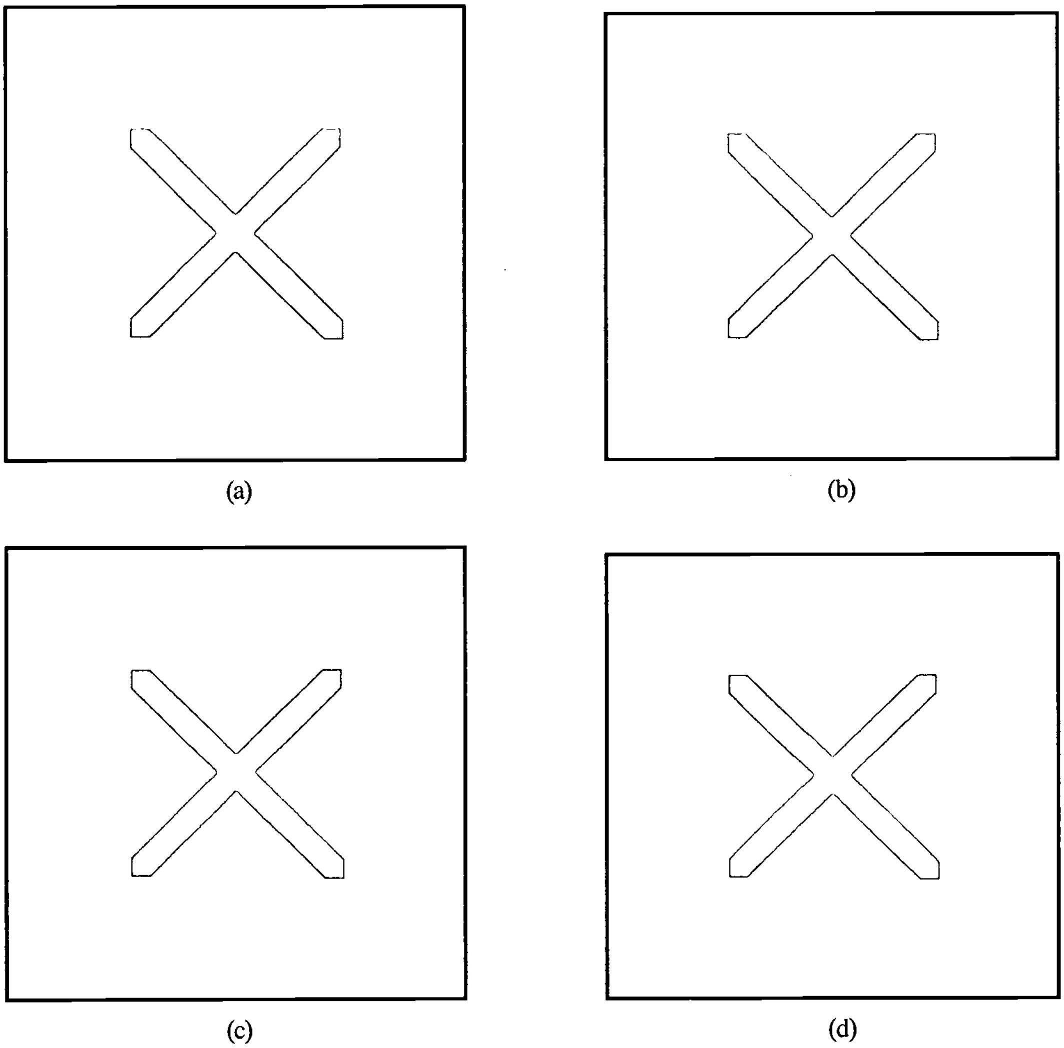


Figure 4. Composite Results from Student Surveys of Classes Listed in Table 1

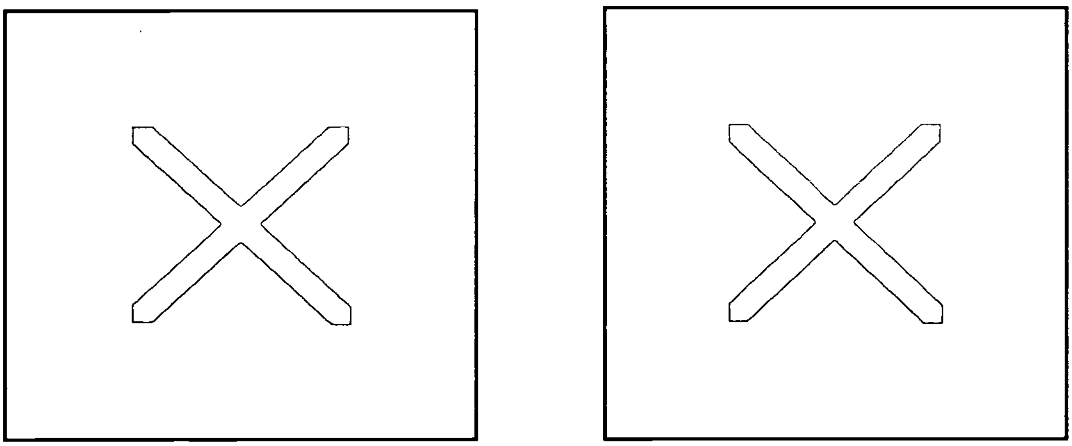
[1] The student survey data collected from the Cleveland site (Suarez & Verde) are something of an anomaly for two reasons: (1) it was the only middle school, and (2) most of the students were native Spanish speakers. The survey was written primarily for high school students and assumes a certain level of maturity and vocabulary in students' ability to reflect on their own learning. It was the opinion of the two teachers at the Cleveland site that their students found it very difficult to understand some of the sentence constructions and were unfamiliar with phrases such as "classroom dynamics." For these reasons the Cleveland teachers felt that the student survey results were not reliable and, therefore, we have not included the Cleveland data in the results of the student surveys.

Each of the four centeredness plots (in Figure 4) above are composite tallies of responses to four statements (see Section 4.8). The methodology used in deriving these four plots was as follows:

1. Tally student responses for each survey statement (gives totals for SD, D, N, A, SA);
2. Merge agreement & disagreement levels (i.e. add SD to D, add SA to A);
3. Reverse totals for negative statements (i.e. switch totals for D to A in L-1, L-2, K-1, etc.);
4. Sum the resultant four component items for each centeredness & normalize (i.e. divide by 4) so totals reflect composite numbers of students.

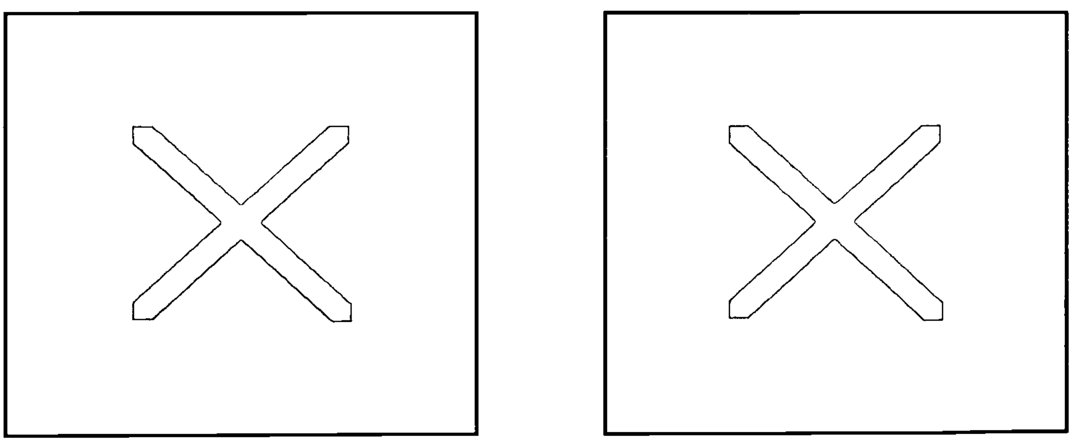
Note: For learner centeredness only three statements were used due to problems with ambiguous interpretation of wording in item L^{-2} (see Appendix 4).

It is of interest to view the components of the data. Our instrument, considered each of the centerednesses to consist of two parts. This was partly for convenience in designing the instrument, but to some degree it is also justified by the theory (see discussion in Section 4.10). For example learner centeredness is "transfer" (from L1 & L-1) and "active engagement" (from L2 & L-2). Separate plots for each of these parts are contained in Figure 5a & 5b. By a margin of over 4 to 1 students agree that using TI-Navigator helps them to build on knowledge and relate new material to things they already know. Also by a margin of about 3 to 1 they believe that they are more actively engaged in TI-Navigator classes than in others.



(a) (b)

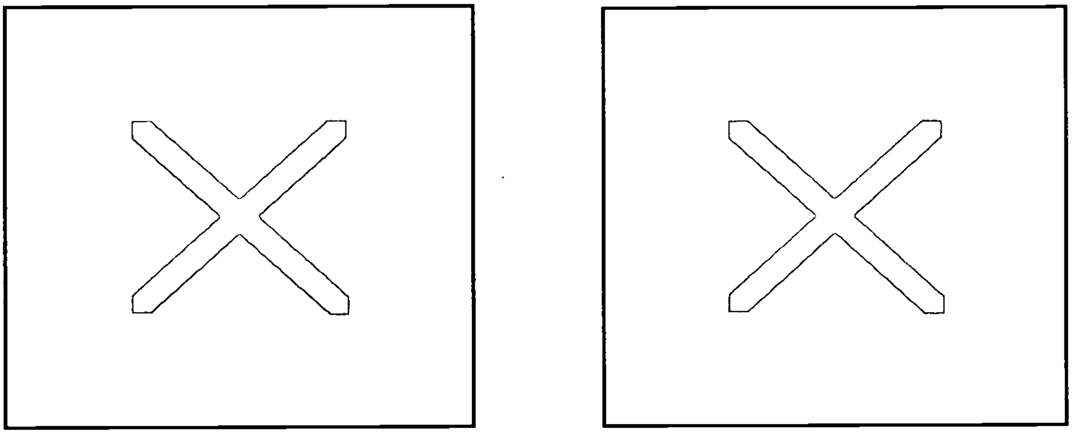
Figure 5. Components of Learner Centeredness from Student Surveys of Classes Listed in Table 1



(a) (b)

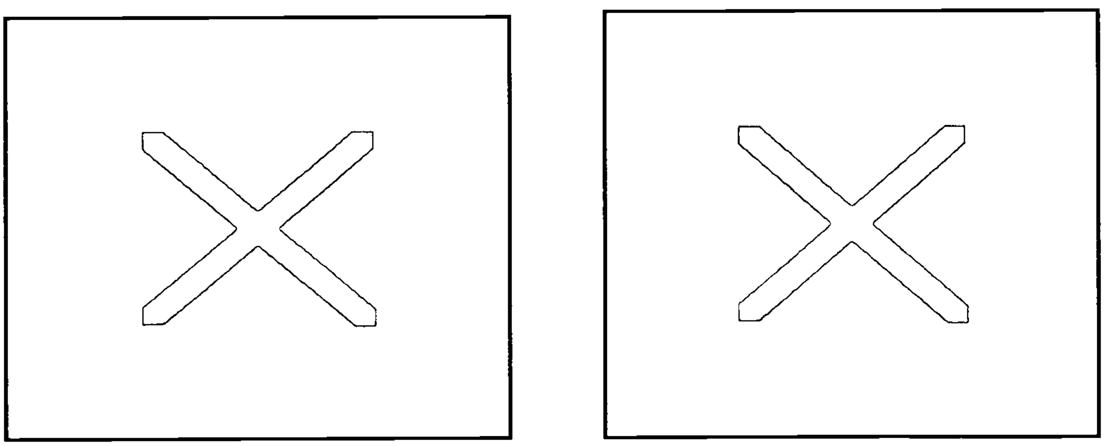
Figure 6. Components of Knowledge Centeredness from Student Surveys of Classes Listed in Table 1

Similarly, in our survey instrument, knowledge centeredness is comprised of, "aiding a better understanding of concepts" (from K1 & K-1), and "application of significant mental effort" (to make the necessary conceptual links to gain conceptual understanding, from K2 & K-2). It may be seen from Figures 6(a) & 6(b) that students agree by a margin of three to one that TI-Navigator helps both these aspects.



(a) (b)

Figure 7. Components of Assessment Centeredness from Student Surveys of Classes Listed in Table 1



(a) (b)

Figure 8. Components of Community Centeredness from Student Surveys of Classes Listed in Table 1

Assessment centeredness is also divided into two parts, namely, feedback to students in helping them to know if they understood (A1 & A-1), and to the teacher in letting him or her become more aware of the degree of student understanding (A2 & A-2). The marked contrast between these two plots is interesting. By a margin exceeding 4 to 1 students believe that they are getting this feedback. However the margin is much less in their perceptions of the teachers understanding of their difficulties. This discrepancy may be due to the possibility that teachers are not accustomed to getting this information and it takes them time to "learn to listen.." (Note: There may be an issue with some misinterpretation of item A-2, so further research is needed in this area. We will discuss this issue more later (see Section 8.7, & Appendix 4))

The two aspects of community centeredness on which our instrument focused, were "classroom dynamics" (C1 & C-1) and "sense of community" (C2 & C-2). Students ratings of both these aspects in the use of TI-Navigator were extremely strong. More than 4 to 1 agreed that classroom dynamics were changed by use of the system and that "classroom interactions resulting from use of TI-Navigator helped my learning." By the same margin students thought that "there is a greater sense of community in TI-Navigator classes than in other classes." We believe that these are extremely important results because as shown later in Section 8, they help to explain underlying processes and mechanisms, as well as relationships to the other centerednesses.

5.4 Student Interviews

Learner Centeredness

"The learner-centered perspective focuses on the knowledge, skills, goals, and cultural beliefs that each person brings to the learning situation" (Bransford, et al., 2000, p.72). In a TI-Navigator class this is facilitated through the possibility of the work that students are doing being available for discussion much more readily than in a normal classroom. The display of results, while it is anonymous, has the effect on students that "because they know it's going to be showing on the TV, that they're trying a little bit harder to get a right answer." (Interview with Hirsch) and "... the fact that everybody got it and I didn't get it makes me think, 'Ok, I'm doing something wrong!' and it makes me want to go back and see what am I doing, because everybody else got it right and I didn't do it right." (Hirsch Students 5,6).

From the students' point of view it seems to be readily apparent that the TI-Navigator helps them to build constructively on prior knowledge. They attribute this partly to the fact that it also helps the teacher to know if they understand knowledge that is prerequisite to gain further understanding. See for example, in the following excerpt:

Kula 3 -

Int: Um, *"Doing activities in class with TI Navigator helps me relate new material to the things that I already know"?*

Girl 4: I think it's because, .. you know how we said that, ... we like to see how .. where we stand in the class; by doing it they get to know, you know, if they do understand past material. Because Ms. Kula actually does it so you know, so you have past material and then you lead up into the new material when we use the TI Navigator, so I think for some people you know it's a way for them to reassure themselves that they do know what we did learn from before, and that they understand the new things.

Girl 2: Yeah, that was a good answer!

Int.: Do you think that's the way her lesson worked today?

Girl: Um ...

Int.: A little bit?

Girl 4: Yeah, I think it was because she gave us a problem on finding just the derivative first ... of the equation, and then we worked on the anti-derivative. So it was like going back to make sure if we know how to take .... Is that what you were asking?

Int.: Yeah!

Girl 3: And then we did the integral ...

Girl 4: and then finally we did the mean value theorem ...

Girl 3: and we just learned that yesterday and so we did very recent material.

In many interviews students bring up the topic of active engagement by everyone in the class. In the following segment, students discuss the local small group conversations that are generated by TI-Navigator activities:

Small 4 –

David: Usually, but it's the same thing. At my table that's how it happens. Most people are like, "What did you put?" and asking me. And, if other people are attentive that keeps me attentive as well.

Girl: It's like no one is really like goofing off and stuff!

David: If somebody's goofing off, I'm gonna get distracted and I'll probably end up goofing off with them.

Melanie: I mean you can tell the difference between like when we're reviewing for a test like with a pen and paper and reviewing for a test with the TI *[-Navigator]*, um, it's completely different, like everyone's silent when we're on ... doing the calculators and stuff. When we're at our desk and our own paper and everything around us, it's like a lot of distractions. A lot of people goofing off. It's like when you have it in front of you, okay, I'm gonna go ahead and do my work and there's nothing really to distract you. It's, all your energy's focused on the calculator.

David: It's a lot easier than writing definitions or anything. It's really a whole lot easier, and I think that's another reason why people would be more attentive to it.

Beth: I think it keeps your mind moving because when one person asks the question it can spark another person's mind and they're gonna have a question and ......

Int.: Yeah??

Beth: And it just keeps going and going, thinking about all these different things. I think you're learning a lot. Always thinking!

As discussed in HPL, we found frequent overlap between the centerednesses. For example, the processes of transfer, active engagement, effort, and formative assessment (i.e. three centerednesses), are all apparent in the following:.

Small 4 -

Int: "I find no advantage in using the TI Navigator to help me build to my knowledge?"

Girl: Hm-m! *[noise of dissent]*

Colin: I disagree! Well helping you build to your knowledge is kind of the same as writing it on paper, it just makes it, overall you end up learning more because you're more active and like in the past questions, you're just more into it. You get, ... it's more fun so it's easier to .... learn different things. I don't think you learn any more than you would any other way, but it's a lot easier to learn because you're having more fun and you're more active.

Int: Hm?

Boy: In class!

David: Also it's like, it probably helps the teacher more than the students just because he can see if he's teaching it right or not, and how many students are understanding it, and what he needs to focus on.

Colin: Especially with classes getting bigger like they are now. Like now, there's a lot of kids in every class, it gives you more of a feeling of you're more like one on one with the teacher and you can always learn better when there's not, ... you don't have to wait on everyone else to ask questions, and you can just, as soon as you put your answer you can wait and get the answer back from what you put in. You don't have to wait on the whole class to raise their hand and ask the teacher if they were right or wrong. So it just gives it, I think ... better.

Knowledge Centeredness

A knowledge-centered environment is one in which transferable skills and knowledge in context are both developed (Bransford et al., 1999). A major aspect of a knowledge-centered approach is, therefore, the building of connections between concepts, between different representations of the same concept, and between previously learned concepts and new concepts.

In Hirsch's classroom, visualization and a focus on the essential characteristics of graphs allowed students "to see how the equation was similar to the other equations that we had seen and where we might start with that picking up with what the vertex was" (Interview with Hirsch). Students see this as valuable to their learning in that "we'll do it in the Navigator and it's a different way. It's like seeing it from a different position and a different angle" (Hirsch Students 5,6).

The issue of "illusory understanding" came up often in the interviews. In the following excerpt, the discussion began with "grades" but quickly turned to issues of effort, understanding, and in the words of Shulman (2000) the necessity of opportunities for learners to "bring the inside outside" and to receive feedback in a timely manner:

Small 4 -

Int.: Do you think if you had been using it all year that it would have made a difference to your grades?

Girls *(all)*: Probably!

Melanie: I would have understood a lot more. I would have, ... you know, the earlier material, we had a really tough time with, and it was a lot harder than stuff we're doing now, so I think it probably would have, because ... I mean, I'm doing all the more better now with it. I mean, it couldn't hurt my grade, obviously, because I would have stayed awake, and really paid attention.

Int.: How about the rest of you?

David: Just like, so many times, I would just like think I had it, ... think I had the concept at the end of the chapter, and I would take the test and completely bomb it. So, ... and like, I had *no idea* that I didn't get it or not. And like, if I had it all year I would probably like been able to tell if I had.

Beth: I agree! I agree with everything!

Carrie: I do too! Because, it allows you to know at the time when you're studying the topic, what you know and what you don't know, and why, and he can explain it to you better.

Colin: I think it helps too!

However, the process of sense-making and understanding can require considerable sustained effort. Using the TI-Navigator system, students are seen to be excited and to want to get things right. The fact that on some activities they can get immediate feedback "gets them more to the level of thinking, 'What was it that I did wrong?' instead of just glazing over the fact that, 'Oh! It's not correct and I don't want to ask about it.' " (Interview with Hirsch). The public nature of information and answers in a TI-Navigator classroom leads to them try harder to get a right answer, "I think it makes you try harder because you don't want everybody else to see that you don't know what you're doing" (Boby Students). Also, the element of immediacy seems to play an important part for some students and this has positive effects on the effort that they apply:

Cantley 3 –

Int.: Um, do you think having to do something with the calculator, to put answers in or something like that makes you think through things, um, that you wouldn't have put the effort into thinking through?

Girl 1: Oh yes! *(Others: Yeah!)* It's much more final when like ...

Girl 2: Yeah and you think, "Oh my gosh, am I ready to send?" and, …

Girl 1: And you're not ready! Like if you just write it down and circle the answer and turn it in, but with this it feels like you're more, … "With it!" And, you're *not* sure! You take, - I take longer doing it on the calculator, because I get nervous. Like once you've said …

Girl 2: It makes you think twice about your answer.

However, it appears that the nervousness referred to above, does not result in adverse feelings about using the system:

Kula 7 –

Girl 2: It's like a hands-on activity kind of thing, and it makes it easier.

Girl 1: Yeah, it makes it easier.

Int.: Oh?

Girl 3: And it makes it more interestin!

Girl 1: Yeah, usually if we do like worksheets, .. all of us just do worksheets, .. and go on the board. I don't find that much fun.

Int.: Yeah?

Girl 2: Yeah!

Int.: So you think generally you're working a bit harder doing it like this?

Girls *(all)*: Yeah! … Yeah!!!

Int.: And you *also* said it's more fun?

Girl 1: I find it funner!!

Girl 3: I think so too.

Using the system also seems to provide a level of pressure on students to think more and try harder. However, they tend to view this in a positive light:

Kula 3 –

Girl 3: I think it makes us answer it, because today when we had the bar graph of all the students that answered, and .. I never answered the question then .. I felt bad because I didn't have my answer in there and you can tell, … so then it forces you to try harder and think to give an answer. …. So that's how I feel, though.

Girl 1: Yeah, because on homework, a lot of us will leave it blank if we don't understand, but by having you know, by having to enter an answer it makes you really, you know, try and figure it out because you want to see if you were right or if you were wrong compared with the rest of the class

… *[a few seconds later]*

Girl 1: Yeah! Because, you kind of want to be right … because you don't want to be the only one who gets the wrong answer.

Girls: *(All laugh)*

…………………

Girl 4: but I know, I guess some people would say, you know how we were talking about how it makes you work a little harder.

Girl 3: Yeah, it makes you try to think on the answer harder.

Sometimes students had difficulties making connections to previous work: "I didn't find any connection of why we needed a Navigator to plug in matrices and then send them" (Hirsch students), or seeing the value of an activity: "I think [the simulation] was meant to be more of a fun activity than teaching us anything" (Hirsch students).

The fact that the TI-Navigator system can run simulations and allow multiple sets of data generated by students to be compiled and displayed, allowed students the opportunity to make connections between

the experiments they have done themselves and aggregated results of the whole classes experiments: "... it's really good for compiling information into one local center. It's great in that respect!" (Hirsch students). Data gathered from many students can be compiled, visualized and understood as a physical process. "Plugging in numbers and seeing what happens ... and see[ing] why what you plugged in does what it does or means. What it means helps me," (Hirsch students).

Assessment Centeredness

"Effective learning environments also require frequent opportunities to make students' thinking visible to see what they are learning" (Bransford et al., 2000, p.69). It is vital for the learning process that students have feedback on whether they are learning concepts that they are working on, and it is vital for teachers to have feedback on how well students are learning concepts. Certain TI-Navigator activities allow students to find out immediately if they have an answer correct; whereas, without the technology Hirsch has found that "if they're doing their regular homework, they didn't necessarily know that they didn't get it correct, so they're still just doing the same thing and not really asking you, because they're not really thinking that they're making a mistake." (Interview with Hirsch). The advantages of this feedback are clear to the students: "... it was quicker, more efficient ... we like that you automatically find out what you made on the quiz." (Boby students).

The fact that students send answers into a controlling computer means the teacher has access to whether students are active or not and, for certain activities, whether they are being successful or not, and it is noteworthy that "...you get more honest answers by using the Navigator. It is anonymous so it's not threatening!" (Interview with Boby).

The advantages of both types of feedback (i.e. to students and to the teacher) are clear to the students as seen in the following conversation excerpt:

Small 4 -

Int.: Um, "Using the TI Navigator does not help in letting me know where I stand on a question?"

Beth: I disagree!

David: I would disagree a lot on that, because like, ... you get like instant results right up on the board, and it tells you if you got it wrong or right, and if enough people got it wrong, he'll know that he needs to go over that, and you'll know you need to go over that - like instantly!

Colin: It's quicker! If everyone had to like write down on paper and turn it in. He'd have to look over all the papers to see how everyone was doing, and then he'd know, ... -- the teacher would know, -- ... what he needs to teach better, and what he doesn't need to teach better. With us all just sending it straight in through the hubs and going up on the board, he knows a lot quicker where the class stands on certain questions and he knows to go over it, ... or, whether he *doesn't* need to go over it, a little more before a test.

Melanie: And I think it's easier on the teacher too, because I mean instead of passing out the papers, having to pass them back and him go through it, and then passing them back out and going over it. It's, you know, like I mean, once he grades it he can like one by one individually know, but he knows right away as a class where everyone stands, instantaneously he knows exactly what he's doing right, and exactly what he's doing wrong.

David: Especially like with block scheduling, when we have to rush through a whole year curriculum.

Melanie: Yeah, exactly!

David: In like half a semester, time's an issue and so he needs to know like right away, what we're getting and what we're not!

Boy: And that helps a lot!

Girl: It speeds up a lot, it really does.

Carrie: And you're able to fix things at the moment. You know, instead of 2 or 3 days. By that time, you know, you've ...

Melanie: You forgot even more. You forgot what the question even *was*!

Carrie: You're able to address the issue at the moment and most of the time you end up learning more than like passing the paper in, because it takes so much more time.

Similarly, in the following, from a different teacher:
Kula 3 -

Girl 3: Yeah, cause if we're all wrong, or if the majority is wrong, she'll go over the concept again.

Girl 1: I think it gives her an idea of where everybody stands in the class, ... so she ... that she knows what we need to review more, ... or you know, we can move on, or not.

Girl 3: And it narrows down the ... what areas we're have trouble with, .. and what areas we understand.

The fact that teacher and students are often surprised by the feedback seems to add an element of excitement that is lacking in other classes:
Small 4 -

Int.: Hm! Do you think you guys get surprised sometimes?

Melanie: Yeah, there were a couple answers today, I thought like, "I thought I knew them," and I was like, "Who whoa, oh wow, I don't know that!!" *(laughs)*

A problematic area with this feedback is that, for some activities, it can focus on right/wrong answers and does not provide a physical record of students making their thinking processes visible. However, spot quizzes can easily be administered to evaluate the knowledge state of the class, "That goes both ways. I know that when a student gets 1 out of 3, or 0 out of 3, then there's a problem, or it's kind of neat to hear them say 'yeah' during the quiz because that's that immediate feedback" (Interview with Boby).

In general, it is clear that the presence of new types of feedback from systems like TI-Navigator, means that teachers have to learn to listen in ways that they did not have to before. This takes time, because realizing that students got the wrong answer or do not understand is obviously not enough. Learning to listen means developing the facility to tease out the cause of misconceptions or missed conceptions, and devise ways to rectify them. Knowing that these problems exist well before a test, actually makes teaching harder because now there is time for the teacher to do something about the problems.

Community Centeredness

The effect of the TI-Navigator system on the classroom environment and classroom dynamics is quite dramatic. There is a strong sense of students working harder and working towards a common goal: "It's more closely knit, the class. Because in a normal class you have people that are sleeping, like they didn't do any homework ... and here you don't have room for that." (Boby students) and, "When we used it, everyone was doing it and everybody was interacting and it made everybody work and I think the class participation went up a lot" (Hirsch students). The public nature of the knowledge state of the class, visible in results on screen, gives rise to discussions of the provenance of answers and provides many "teachable moments" because misconceptions are made visible: "... we're all connected to the same system so we can see each other's mistakes, where before we would just do [our work] individually," (Hirsch students). Furthermore, students are less afraid to admit mistakes because of the more free flowing nature of information in the class. Some students felt that the sense of community arose form the novelty of the system and did not impact their learning: "I think the sense of community

comes just from being something that's experimental but I haven't felt like I've learned very much" (Hirsch students). Others felt that technical problems with the system and efforts to overcome those were the source of the community feeling, "Everyone was helping everyone else figure out what to do but if it worked properly, then I don't think that everyone's community would be going on." (Hirsch students).

The TI-Navigator classroom is a very interactive environment. Students are presented with multiple representations of knowledge such as symbolic, visual, and simulated. The TI-Navigator classroom is one in which there are class discussions arising out of shared information as well as collaboration and a feeling that something novel has happened: "It's more student based. You're not just looking at chalk boards" (Hirsch students) and "they feel afterwards that, 'Hey, that wasn't just your standard old math class that I sat in!'" (Interview with Hirsch).

Kula 3 -

Int: Class dynamics are not affected by the use of TI Navigator?

Girl 4: I guess that's why everyone disagreed, cause I think it does change the dynamics of how our class is! I mean, more interaction. You know, ... I guess since we're all .. I said connected before, we're all connected ... and I guess if we don't have the TI Navigator we're just sort of in our separate note-taking little world, you know, but with this .. it's like we're actually working together. It's kind of nice that we -- I mean I kind of like the classes that we use it -- because we don't have to take so much -- so many -- notes and you know, it just ... it's just a different way of learning. Otherwise, we'd just be listening and taking notes and not talking at all, but this is something where we can talk about it and understand it, .. so I think if we had a mix of taking notes and listening, and of the TI Navigator it would really balance a class .. where we could feel like we're having fun (laugh)

Girl 3: Yeah!

Student Feelings and Behaviour

It is clear from the data that the use of the TI-Navigator system has engendered strong feelings in the students: "They're excited about using it ... and kids get upset when they get questions wrong on it" (Interview with Cathy, 2002). The students found the technical difficulties in using the system very frustrating: "Like today, as a matter of fact, it took me six tries to [log] in. Other days if you weren't getting in or you got behind, you are frustrated and you were ready to quit" (FG1, 2002). There are problems in the prototype of teachers using the system where it may not be most appropriate in an effort to use the system as much as possible: "I think maybe in a different chapter it would apply better than the one we're working on now. When we did the matrices yesterday I didn't really see what we were doing with that" (FG1, 2002).

The use of the TI-Navigator system has some positive effects on what students do in the classroom: "students pay more attention when we're using some sort of hands-on device" (Interview with Cathy, 2002). Students are also found to be actively engaged both in their own work and in class discussions. Students find the class can give them some momentum and keep them engaged: "It kind of keeps it going. It's easy not to be too shy" (FG2, 2002). The slowness of the system can cause problems with engagement: because we were sitting in a group and we were goofing off after about 30 seconds" and "I remember one day we sat there and didn't learn anything that day because the teacher spent all hour trying to figure out how to operate it " (FG1, 2002).

5.5 Teacher Surveys

The teacher survey was similar to the student survey in that it was constructed from eight pairs of confirming and disconfirming statements and designed to reflect aspects of each of the four

centerednesses. Also each one of these statements paralleled the corresponding item on the student survey as can be seen from comparison of the two instruments contained in Appendix 2(c) and 2(d). The composite results for the same eight[2] teachers are contained in Figure 9 below. These results show that most teachers responded positively (agreed or strongly agreed) to statements about the extent to which working with the TI-Navigator enabled aspects of the HPL centerednesses in their classrooms. As described in Section 5.3 for the student surveys, each of the four centeredness plots (in Figure 9) below were the composite tallies of responses to four statements. Components of the data making up the four centerednesses are shown in Figures 10 through 13 for learner, knowledge, assessment, and community centeredness respectfully.

[2] Because we wanted to compare teacher and student survey results, Suarez and Verde's results are not included in this section.

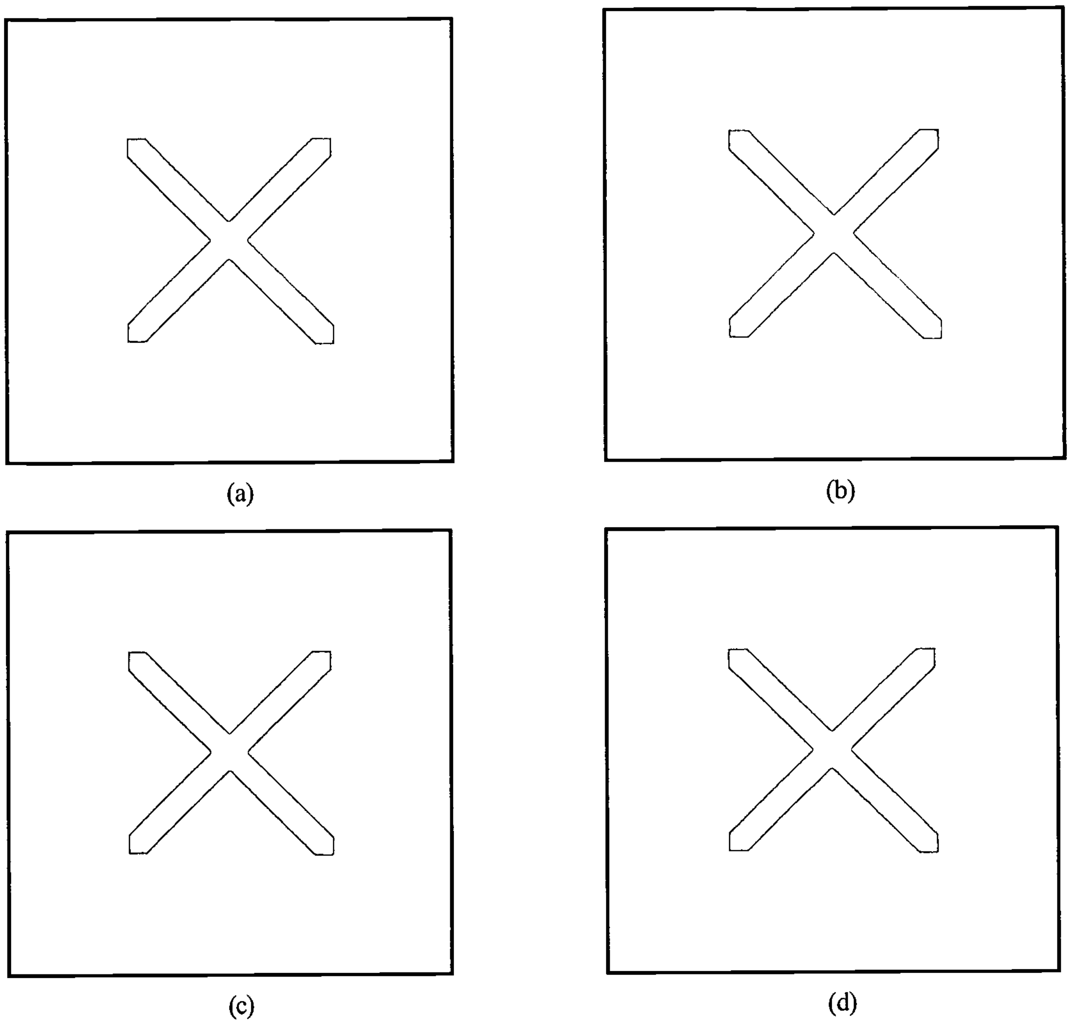


Figure 9. Composite Results from Surveys of All Teachers Listed in Table 1

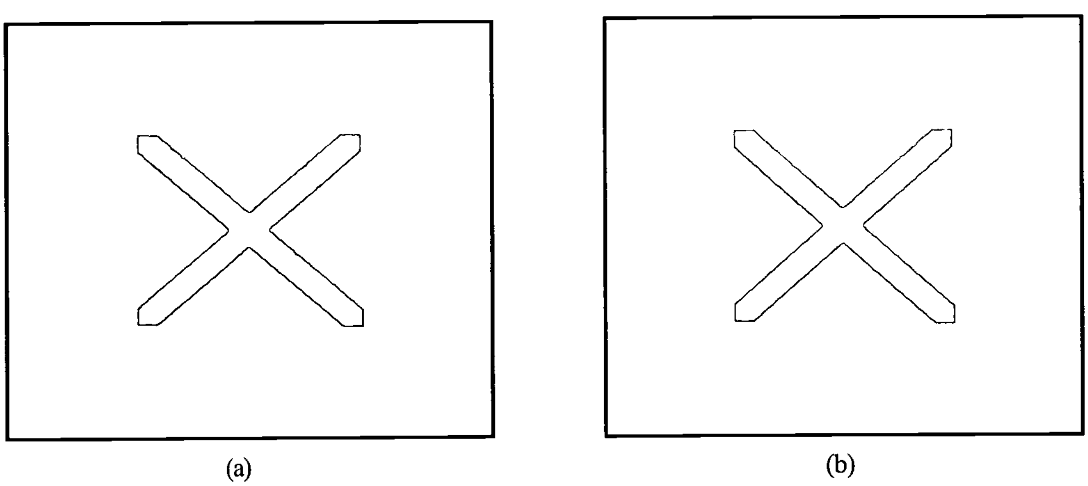
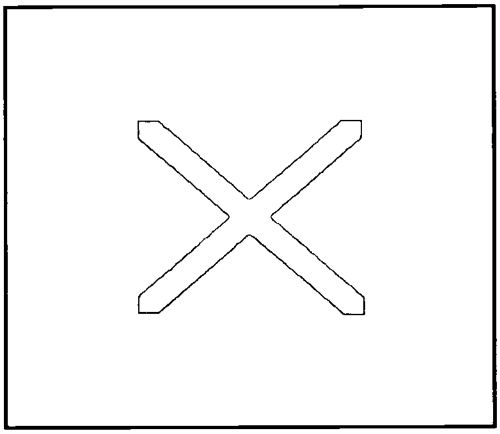
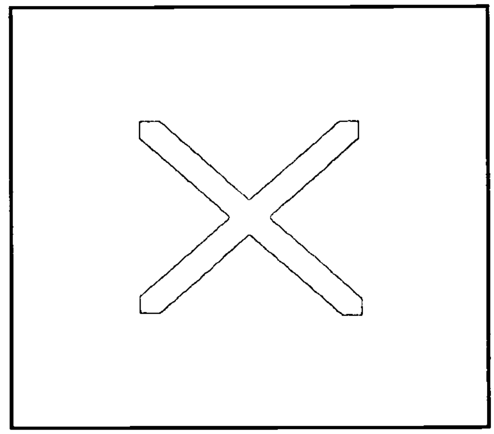


Figure 10. Components of Learner Centeredness from Surveys of All Teachers Listed in Table 1

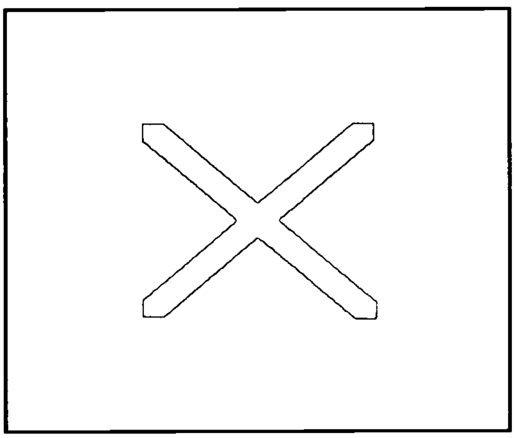


(a)

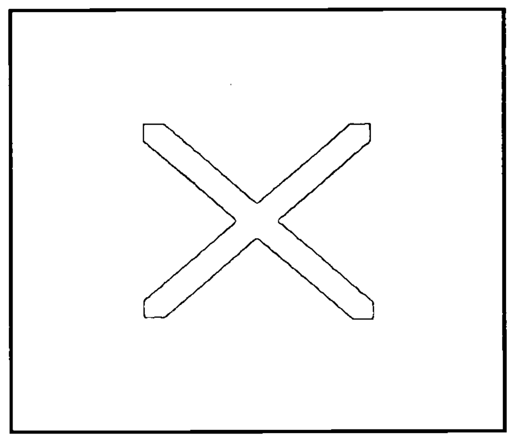


(b)

Figure 11. Components of Knowledge Centeredness from Surveys of All Teachers Listed in Table 1

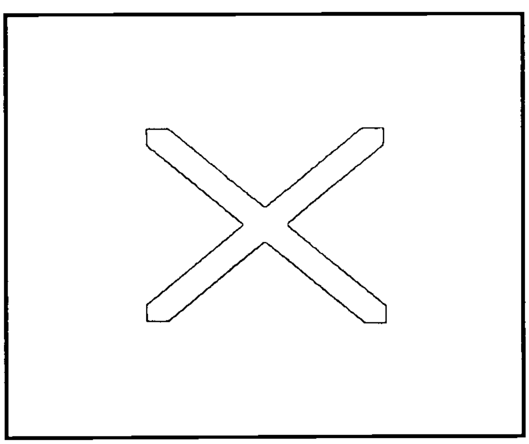


(a)

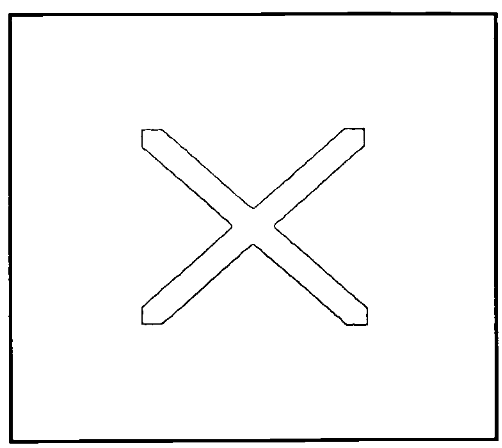


(b)

Figure 12. Components of Assessment Centeredness from Surveys of All Teachers Listed in Table 1



(a)



(b)

Figure 13. Components of Community Centeredness from Surveys of All Teachers Listed in Table 1

TABLE 3. Breakdown of Individual Teacher Survey Reponses from Teachers Listed in Table 1

TEACHER	Total Number for Each Teacher		
	D	N	A
KULA	2	2	12
CANTLEY	2	4	10
HIRSCH	3	0	13
BOBEY	2	0	14
SMALL	1	2	13
ELLIS	0	4	12
KEGERIS	1	2	13
SUAREZ	0	0	0
VERDE	0	0	0
DRISCOLL	0	3	13
	11	17	100

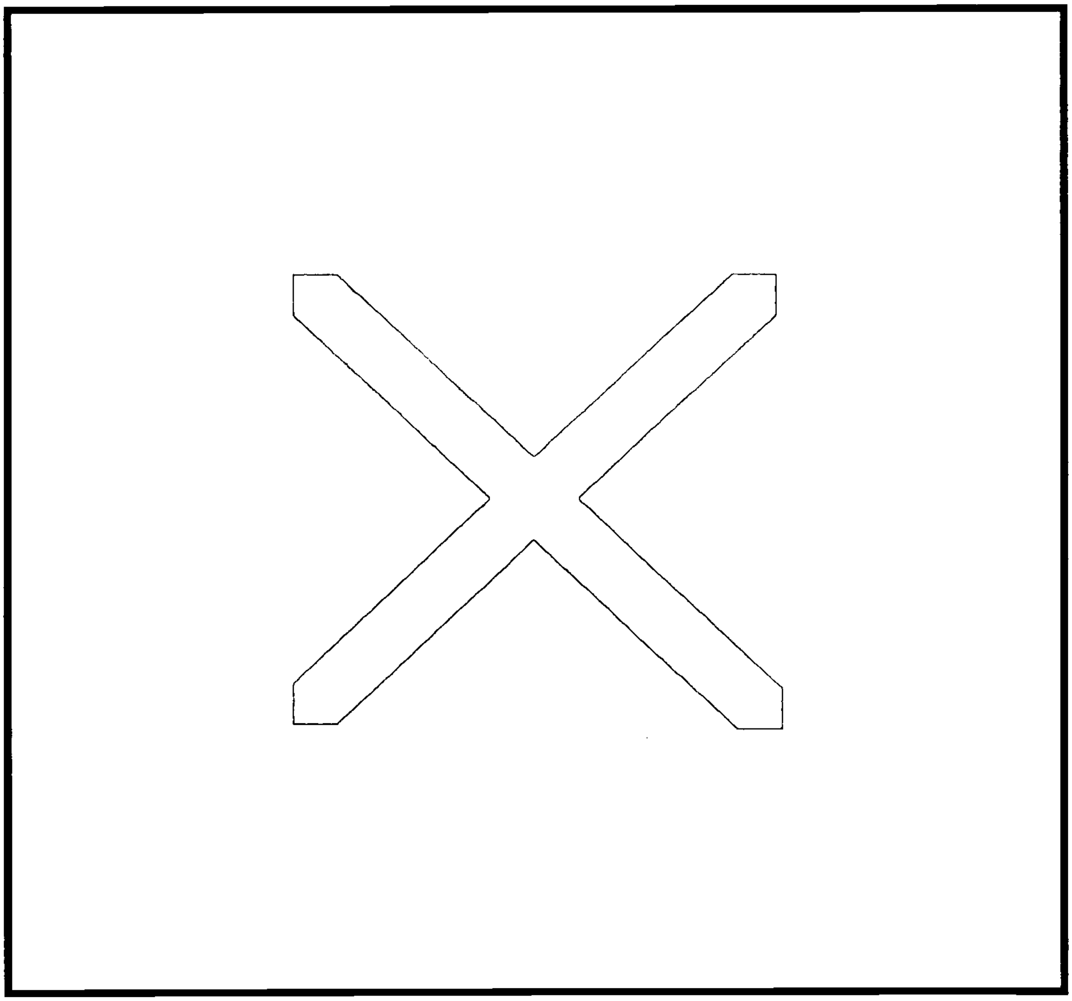


Figure 14. Comparison of Average Positions Taken by Teachers and Students on Issues Related to HPL Centerednesses in Teacher & Student Surveys

It may be seen that every component produced a positive result, with a majority of teachers agreeing in every case. However, because of the small number of teachers and the focus of this research program it is interesting to ask the question if it is the *same teachers* every time who are either neutral or disagree with all the component propositions. From the data in Table 3, it may be seen that this is not in fact the case. While, in every case (except for assessment centeredness regarding feedback to the students), all teachers were not unanimous in their opinions, all were remarkably consistent in their overall level of agreement with the propositions in general. For example, no teacher disagreed with more than 3 out of 16 propositions, and the minimum number of agreements for any one teacher was 10 out of 16. In this particular case, the teacher in question was the very teacher who had used the system the fewest number of times and who had also experienced significant system problems (bugs).

In general, when compared with their students, the teachers are even more positive regarding every component issue of the centerednesses (see Fig. 14). However, with two notable exceptions, data from both students and teachers show strikingly similar overall patterns, as can be seen by the relative heights of the bars for both in Figure 14. The two exceptions are in the assessment centeredness component "feedback to the teacher" where teachers generally believe that they are understanding student conceptual problems better than their students believe they are doing this. That is, if one compares students' views of the two components of assessment centeredness, students believe that they are getting strong feedback on their understanding. But, while some think the teacher is also getting this feedback, a significant minority believe that the teacher is not getting it (see Fig. 7b). However the teacher data shows no such characteristic. We believe that this may point to a very interesting conclusion. Namely, that teachers are indeed getting much more and better feedback than before without TI-Navigator, but they also have to learn to listen. This is likely to take more time than the 1 to 3 months which the test group of teachers had in using the system. Listening is also more complicated than it sounds, because truly listening and understanding students' conceptual problems involves more than assimilating the fact that such difficulties exist. It also includes discerning possible causes, devising techniques how to diagnose them, and developing strategies to remedy them (see further discussion in Section 8.7).

5.6 Validity of Teacher Data, Teacher Attitudes, Technical Problems, and Effort

We are aware that in some respects, it may be said that our teacher data could be inherently less reliable than our student data. Such an argument might be based on the fact that our test-group of teachers,

a) wanted to work on this project,
b) they became committed to it, and,
c) wanted it to be a success.

The purpose of this section is not to counter such an argument, because we suspect that they are all true. However we would dispute the conclusion that, because of this, our teacher data is unreliable. In this section we wish to lay out some of the background regarding selection of the teachers, and the situations they faced with the equipment and adaptation of pedagogy, while still facing all the normal intense pressures that teachers face every day in their professions.

Our teachers were not randomly chosen. They came from a group that was already self-selected by the facts that they:

1. Were sufficiently cognizant of new developments in their field to hear about TI-Navigator, in the first place;
2. Had, of their own volition, come forward to express interest in using it, and they had written a proposal to TI for doing this;
3. Could obtain the support of their school systems and persuade them to come up with money to pay half the cost of a system;

Also, they were selected by TI on the basis of experience in using graphing calculators in their teaching. That is, only experienced users of graphing calculators were considered as possible initial recipients of the TI-Navigator, under TI's half-price introductory offer.

In addition, to participate in this project they had to be willing to spend a week of their Summer vacation, unpaid in Columbus, attending our NSF sponsored TI-Navigator Institute. Further, after TI postponed the commercial introduction of the system, the final test-group teachers had to be willing to accept a prototype that they were aware would malfunction from time-to-time. And, certainly when they made the decision to participate in the final test-group, they were all aware of the significant pedagogical challenges posed by this new form of technology, and the concomitant effort that they would need to expend in figuring out how to use it effectively in their classrooms.

Then, after they began using the systems, it became clear that some teachers were at sites which were experiencing huge technical problems with the systems, due mainly to the fact that all data had to pass over the internet through TI in Dallas, and firewalls, or connection slowness, could make a system almost unusable. After visiting a teacher's classroom at such site, one of our researchers commented that the positive attitude of the teacher was remarkable. And, that under similar circumstances to what she had experienced, he ... "would have thrown the system in the trash long ago!!" There was also another source of technical problems. The TI-Navigator was designed from the "ground up" to be programmable. Thus, there were over 250 programs available for teachers to use. Some of these programs worked better than others, and some contained bugs. Unfortunately, sometimes the more adventurous and imaginative a teacher was in their use of the system, the more bugs they discovered and the more their system crashed.

Any technical problems in a classroom are a huge issue. They disrupt the flow of a class, cause students to lose focus, and make planning very difficult. For example, if a teacher plans to cover a critical issue using the system and technical problems arise, the first thing that happens is that time is lost. Perhaps the system can be made to work, but by then the attention of the class has to be recovered, and there may not be enough time to cover the issue in the way that it was planned. If the system cannot be made to work, then the teacher has to think of an alternate way to cover the issue, in the time remaining. This can be particularly problematic if a hard deadline like a test is planned within the next few class periods, because the students may not be properly prepared. Other difficult issues arise when everybody in the class is "fine", and only one or two students are having technical problems. If the teacher takes time to sort out these problems, the rest of the class loses focus. If the students with difficulties are simply told to watch the rest, this is not fair to them and they feel particularly left out if the rest of the class is "having fun."

Our test group of teachers had to cope with these and dozens of other problems which we cannot begin to describe in this report. We have also tried to indicate directly (see Table 1), the relative degree to which individual teachers experienced technical problems. Another issue was the fact that our test group teachers had to introduce the system more than half-way through the school year. This was problematic as one of the teachers explains:

> **Boby:** Yeah, but even - I'm still teaching but I cannot effectively introduce something this different that late in the year. It was hard enough to introduce this at the end of January. I would love to have had it - and I will look forward to having it next year from the beginning of the school year and I think it will be a more natural part of the class.

In conclusion, this research team feels that we owe every teacher in our test-group a great debt, and feel that it behooves us as researchers to listen carefully to what they have to say.

5.7 Teacher Interviews

Our approach in this section is *not* to summarize the opinions expressed in the teacher interviews. Because of the link between the teacher survey data (described in Section 5.5) and the interview topics, we feel that this has already been accomplished. Rather, we hope here to illuminate the reasoning why this group of teachers is enthusiastic about CCS technology, and what they see as its potential for improving teaching and learning. As before we group their comments under the general headings of the four HPL centerednesses, although it was only the constituent components, and not these constructs themselves, that were explicit in our interviews with the teachers.

Learner Centeredness (Transfer)

Reasons given by teachers as to why they thought that the TI-Navigator assisted them in helping students to build on previous knowledge are summarized in Figure 15 (Box 1). These relate to being able to assign questions, tasks, and activities that will

a) Show existing conceptions that students bring to the setting; and,

b) Extend and make connections with previous knowledge.

For example,

Cantley: Well, I disagree! Because, I think Navigator *does* give you an advantage to help the students build on their previous knowledge.

I: Yeah?

Cantley: Because you can, after you get their response, you can um explain it, or not explain it, they know and if you give them another problem along the same line, you know, "stair step them" then so it would help them. So that's why I said no, because it's a negative question.

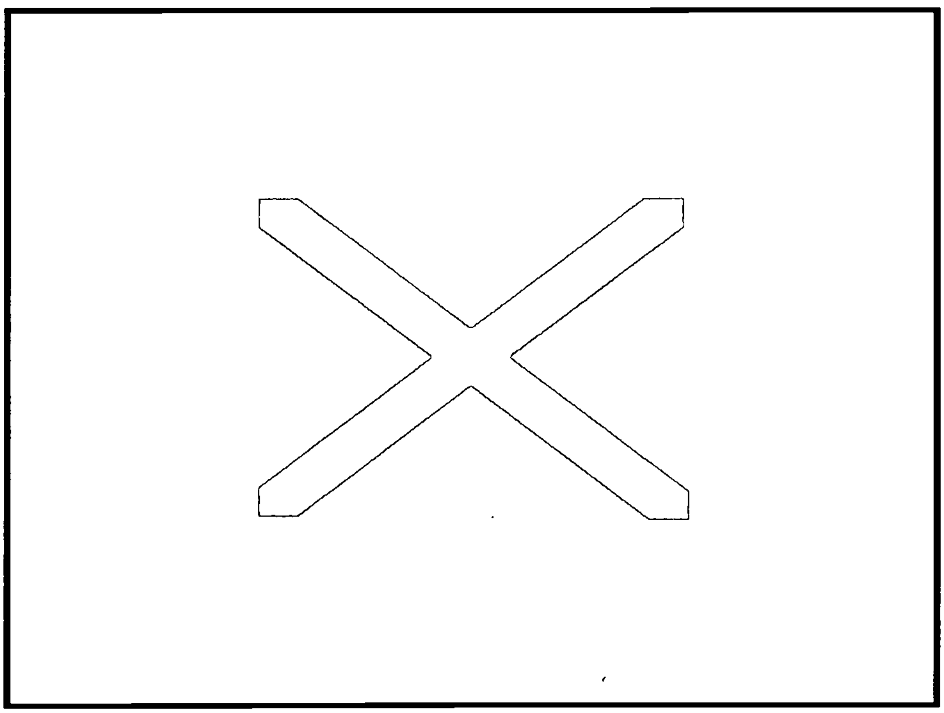


Figure 15. Aspects of Learning Environments which Appear to be Catalyzed by Wireless Networked Graphing Calculators

And,

Boby: Oh yeah. I can ask them a question, before I even get started, to know how in depth I should go into something. I have a very wide variety in my classes because I have - especially

my 11th grade students - they're coming from different schools from all over the state of Arkansas so Algebra I in Little Rock Central may not be the same as Algebra I in Podunk High in Delta or something.

Also, some teachers reported noticing during the dynamic classroom interactions that Navigator tends to promote, that students were going through the process of building on past knowledge:

Small: ... when they had to argue, many of them - to my great pleasure - would bring back things that were discussed in class earlier or days before, in their arguments. So obviously, they're making connections if they're arguing on, "Why this particular diagram of refraction is better than this diagram of refraction?" then they obviously have to be knowing some things about refraction. They obviously have to know how those light rays are traveling,

But, there were also comments on the limited capabilities of the software:

Driscoll: I think Texas Instruments has to do a better job in red flagging students .... *[and keeping records to help me]* ... see who is having difficulty ... flag students that are having difficulty so that not only do I see the raw data, - that's still important to me - but I see the data that's been compiled and say this student got 40% of the questions that I asked.

The ability of the network to share data was also mentioned, as presenting opportunities for students to relate to more realistic data and make connections between mathematics and everyday experiences:

Small: We've done a lot of labs, we've done graphs, we've done best-fit lines, and so forth, looking for regressions and correlations, ... when we would look at the list of data that some data was not good, ... we went through and eliminated bad data. Ended up, everybody had a good set of data, and then they had to go through the calculator process of plotting this graph out and doing a regression line and looking at the relationship and making those connections. And in that, "they were building," and I was very proud of them. It's one of those moments as a teacher when you see the class making those connections and building on something that you haven't covered in a long time, and seeing the excitement of people going, "Hey this works! We actually, I did this!" .... and I don't know, ... it made me feel good to see some eyes light up and some understanding taking place as they were actually getting a graph and finding the connection and making that, ... you know inverse square connection between those two factors.

And, from a different teacher:

Boby: Getting data and stuff it's nice! I can have students conducting experiments and type their data in L1 and L2. They might do it once or twice and have just one or two points in L1 and L2. They dump it to Navigator and take the whole class back. Then they quickly have 40 or 50 points like that. The data collection is ... that can go all the way from basic math to calculus, you can do data collection activities.

Simulations were also considered to be an interesting capability to link what went on in class to the real world:

Small: We played with the disease one, we played with the elevator one, ... just to show the kids what we could do, and in general those worked pretty well. I was rather pleased. ... I think the potential was great for those interactive ones like that. Um, I think overall I think the kids were pleased with it and it showed them a lot.

Hirsch: The kids really have enjoyed the simulations that we've done, ahhm, I think they feel afterwards that "Hey, that wasn't just your standard old math class that I sat in." You know

where "the teacher showed me how to do twenty problems and I sat down and did twenty problems."

Learner Centeredness (Active Engagement)

Almost all teachers mentioned that students are more actively engaged in their classes as a result of using the TI-Navigator. They had many reasons, but the foremost ones tended to be focused on an "appropriate" amount of pressure for students to think through issues, establish positions, and commit to positions (box 2, Figure 15). The teachers felt that the source of this pressure came from the fact that what students did (or didn't do) was readily available to the teacher:

Kegeris: For the most part because they know that I'll know, whether they're working on it or not, I could tell by taking a look at the teacher console - rather than just walking around the room. I can't help but stop to do that.

Small: When I ask them to do something and they're connected and obviously I know whether they've done it or not because I can see there are 23 people in the class and only 19 people have responded …

They also pointed out that this fact also tends to encourage students to apply effort, even to difficult tasks, that they might otherwise avoid:

Cantley: But yeah, it's, … when they have to do, … all of them. Like today, I gave them, like a practice quiz. I put a bunch of problems across the board, and they can pretty much do them in the order that they want to. So, most of the time they'll see one that's a little difficult, so they'll skip it, so in that sense they're getting away with not completing the action with what is going on. But, with Navigator, they have to do the problem and they have to put it up.

Some teachers also pointed out that, because students are aware that other students will see on the public classroom display, that someone's answers are missing, they don't want to be that person:

Cantley: Well it encourages, almost forces 100 percent, they have to do the problem, they have to send it in, and then everybody is going to see their answers.

However, most teachers also felt that there were additional dimensions to the enhanced student engagement that they were seeing. Some expressed it as excitement among students that had not been present before:

Hirsch: … they walk in class and the see the Navigator is hooked up they're all like, "Oh, the Navigator! We're going to use it today!" They're excited about using it, and they ahhm, they're really, like, paying attention to what's going on, how we're going to be using it. You know: what do I want. And kids get upset when they get questions wrong on it.

Hirsch: And I've had some kids, like one student, when we were doing a parabola activity, got about 60% and he was like "Oahhh! Can I go back and do it?" "I can't handle the 60!" … So I see that as they're there using the Navigator they seem to be wanting to use it. Wanting to get things right and really kind of staying in touch with the things that are going on.

Some teachers felt that it was the simple fact that this was "technology" that created the interest:

Verde: Absolutely. Because it is like the, "Game-boy generation!" … the video games, … and they like to have something that they are manipulating.

Small: They're certainly doing what I'm asking them to do because it's novel, it's interesting, they're working with technology and these kids that's their lives, they've come up in an area of technology, so being on task …

Driscoll: Today, -now maybe I saw something different than you - I think for the most part that we're engaged, but as soon as I put down the technology and started going to the board work I think there was a shift in their ability to focus.

However, there also tended to be a sense amongst the teachers that the effects they were observing were due to more than novelty associated with the presence of new technology. Specifically, they mentioned,

(1) "interaction" with other students:

I: So, you're drawing a difference between being actively engaged and being on task.

Hirsch: Right.

I: Ok, so talk to me about that?

Hirsch: Ahhm, well, what I said before, I think with the Navigator, ... being actively engaged, - because they are directly looking and finding right answers and comparing stuff with other people, - that they want to be getting those things right. So they're more engaged in their activity. They're thinking about what's going on with the activity, where sometimes when they're just doing homework they're on task.

I: Ok?

Hirsch: But it's kind of like, "On task going through the motions!"

(2) the effect of a "level playing field":

Verde: When you ask a question, always the same kids answer it. And the other ones, they sit back and they no do it, "Anna will answer the question!" and they don't participate. In the Navigator everybody participates. It's a specially designed equal playing field and I think that's one of the major advantages.

(3) and, not wanting to feel "left out":

Verde: I noticed that they do the homework; if they don't do it they can't use the Navigator so it's also a motivational thing. In the morning when they first come in, "Did you do your homework?" "We're doing Navigator homework send-in today!"

Knowledge Centeredness

Teachers attitudes with respect to knowledge centeredness tended to focus on their enhanced ability to reveal diagnose and remedy misconceptions, and thus aid in a focus on achieving conceptual understanding (see box 4, Figure 15). Tim Cantley explains:

Cantley: *"Using the Navigator does not help improve student understandin?"*. No, I disagree. I think it *does* help improve their understanding. Whenever a teacher can get feedback before a test or quiz, and see if there's a problem, and you can help them understand it, or re-explain it another way then I think it's a big help!

Many teachers mentioned specific examples when this had occurred in their classrooms. A few of these follow below:

Suarez: ... we were doing patterns for geometry, ... because we built the tetrahedron. And trying to get them to come up with, because the pattern was, "four raised to the power," and a lot of the kids instead of raising it to the power they put, "multiplied by." And so, then we discussed the difference between multiplying and exponent.

Kula: Um, I was ***not*** expecting them to miss, the first question. I was really expecting it to be a lead in, "This is a piece of cake, I've got it, I'm ready to go!" and we wound up having almost more discussion on that one than we did on the later questions. But, um, with

overlapping similar triangles I saw consistently in their work that they were missing the whole side of the larger triangle and just taking the piece that wasn't overlapping, and so I was using the advantage of Navigator to help talk about that idea again and then get ready to move on. *[then describes what she had intended to cover, & adds ...]* ... but I think in the long run the discussion that we had about where their misconceptions were, was more valuable.

Some teachers also frequently mentioned that the students began asking "Why?" -type questions. For example,

Hirsch: So then they'll know if they got it incorrect, then they're raising their hands going "Why did I not get this correct?" Where if they're doing their regular homework, they didn't necessarily know that they didn't get it correct, so they're still just doing the same thing and not really asking you because they're not really thinking that they're making a mistake.

Another teacher mentioned the fact that he had found Navigator increased students' desire to learn:

Small: I think the Navigator has a great potential to affect the overall classroom and the perception of a class. Because I think students enjoy learning. No student enrolls in a class, whether they have to or by choice, in order to earn an "F". I mean you don't go into something expecting to earn a failing grade. And most students want to learn! It's a good feeling to learn. Whether they admit it or not, they love learning overall, and if they feel that they *are*, you create that positive atmosphere, and I think there's where the inherent potential of the Navigator lies. In a very unassuming way it creates a community of learners. Not that it didn't exist before, but it's just another tool to improve maybe the desire, or to improve the feedback, or to improve the potential of the student, or for the student.

This was echoed in a different way in the situation described below:

Boby: ... she says to the girl next to her, "Oh yeah, this makes me try harder to get the right answer because I know he's going to see it!" and so she said that without me even asking her. So I know that for some of them they may not admit it to your face, but they know that I'm seeing it.

Assessment Centeredness

The test-group of teachers were unanimous on the topic of significantly improved feedback to the students. They felt that this feedback provided students opportunities to reverse and improve the quality of their thinking and learning (see box 3, Figure 15). For example:

Hirsch: So to me that was effective because they're getting it wrong, and they know right away they're getting it wrong. Now "Why?" and "How can I go back and fix it and change it so that it's correct?" So that, ... that was effective for me thinking that they know that it is wrong, right away! Where if they're just graphing it on the paper, "they can graph twenty of them and never realize ...!!!"

Also, the issue of timeliness was mentioned by many of the teachers (as well as the students themselves). For example:

Suarez: ... then we can look at the answers and compare. So in that way they get to, ... more immediate feedback than if they hand it in, and I give them back the next day.

Unsurprisingly too, the teachers were very positive on the fact that they received improved feedback which gave them cognizance of class positions, and a window into any misconceptions (see box 4,

Figure 15). A crucial factor in this regard for teachers, was timeliness as seen in the following examples.

I: *"Doing activities in class with the TI Navigator um, helps me tell if the students understand the concept ?"*

Cantley Yeah! I agree with that because I get immediate feedback and if I give them a basic problem and they get it right then I know that they understand the basic concept! And, if I give them a little more difficult problem and they have one little problem with it, "I know!" It kind of gives me an idea of their level.

Verde: "They really like it!" And, the instant feedback that both I get, and the students get - when I can see there's a problem right away I know what I need to do, so that they can! I think it clarifies something, ... I can go back and do it right away instead of waiting till I give them a test. And, I can see that they didn't get it and we need to go back to square-one, and then do the whole thing over again. There's instant correction on the teacher part. And it will help the students.

As a result of this feedback, the test-group teachers also tended to find themselves changing pedagogical direction on the fly, and perhaps altering their entire lesson plan for the day:

Driscoll: What I'd visualized doing this morning was really completely different from what actually transpired. What I had planned on doing was *[describes his original plan for the class period]* ... and the assessment that I had planned using the Polling Facilitator wasn't done on Friday, ... so I had to finish that today ... but as soon as we got to the question about length of the pendulum and whether or not the graph that they saw meant that we have increased or decreased period, was a 50-50 concept. "That was a problem!" ... That's why I had to go fix the equipment. And, then we did the simulations and I think that was effective. I think that the students ultimately came to the understanding that I had wanted.

A very important and interesting result of this accelerated feedback tends to be that the teachers begin to say that they are becoming "better teachers":

I: Do you think Navigator has the potential to make teachers better teachers, ... for some of these reasons?

Small: If a teacher is willing to look at what the students are telling him, and the students are honest (and I think that the Navigator lets them be honest), um, you can learn a lot. You can improve. Um, there's a great opportunity to learn about how you teach by looking at how students respond to what you're doing. I don't know if some people want to do that though! But, I've learned a lot in just the few weeks you know that we've really gotten into it.

Community Centeredness

In HPL, the authors show a diagram (as reproduced in Figure 1) which is intended to represent the way in which the four centerednesses relate to one another. In this diagram, they show learner centeredness, knowledge centeredness, and assessment centeredness as three overlapping circles. But, community centeredness is shown differently. The authors of HPL did not show it as simply another circle, that overlapped like all the others. Instead, they drew a fourth circle that was larger than all the rest, and fully enclosed all the other three centerednesses. This fits our own conception of community centeredness exactly, and we believe that the research data in this report even serves to extend the all-embracing nature of community centeredness, as described in HPL.

In fact, one of our conclusions from this research work tends to show how community centeredness seems to provide a key to understanding the genesis of a new classroom community. In writing this report, we felt that the importance of these insights was sufficient to warrant special treatment in a separate section. Thus, we defer discussion of the teachers' comments on the components community centeredness to Section 8.

6. RESULTS FROM EXPERIENCED TEACHERS

6.1 Reasons for Including Results from Experienced Teachers

Almost as an afterthought, while we were analyzing results from the test group of teachers (Table 1), we suddenly realized that there could be substantial, value in also obtaining results from teachers more experienced with using this CCS technology in classrooms. There were basically two reasons for doing this:

1) Validation of instruments; and to,
2) Attempt to extract some measure of longitudinal dependence for the types of changes which we were already seeing in classrooms of the test-group teachers.

Some background to these intentions is as follows. In earlier NSF supported work (from '90 to '95) with classroom communication systems in university physics one of the PIs on this grant (Louis Abrahamson), had observed that professors' ability to exploit the pedagogical advantages of a CCS. was typically still improving after two or three semesters. These observations were based on situations where professors typically used a CCS in every lecture period. Although these impressions were subjective and never formally reported, it seemed reasonable to suppose that a similar characteristic might possibly be expected from the group of test teachers in this project. That is, the HPL centerednesses could increase over time as a teacher becomes more comfortable with the technology and with how to apply it in pedagogically effective ways

If this were indeed to turn out to be the case, then obtaining data from teachers who had longer experience with the technology should simultaneously provide two results. First, it should add validity to the two major positivistic assessment instruments devised for this study (the student survey and teacher survey), and it should do this by also showing a second result namely, a degree of longitudinal dependence in the HPL centerednesses. Ideally, the approach best suited to obtaining this type of result would have been to actually take successive measurements in the test classrooms over time. However, due to the limited exploratory nature of the study, this was not possible. The next best solution was to attempt to simulate the effects of longitudinal time dependent data by also collecting complimentary data from the group of teachers who were already part of this project and had longer experience in using the technology.

6.2 Who were the Expert Teachers?

In addition to the group of test teachers who were new to this technology, we were fortunate in having three teachers with two or more years experience in using these systems in their classrooms. These experienced teachers were actually the same group who taught the Summer Institute under this grant (in August 2001 at Ohio State University), to the test group of thirty three teachers. All of these CCS-experienced teachers taught in public high schools which drew students from predominantly blue-collar neighborhoods. Two of these teachers had used prototypes of the TI-Navigator system and its predecessor test systems at the same school in Columbus Ohio, since Fall 1998. The third teacher began using a prior system (Classtalk) in January 2000, and then switched to the TI Navigator prototype in Fall 2000 , at a high school in Levittown, on Long Island, NY.

6.3 Results of Student Surveys from Expert Teachers

The results shown in Figure 16 are based student surveys of all three experienced teachers listed in Table 2. For comparison purposes the same figure also contains results from the eight test group teachers from whom we had good student survey data. The principal difference between these two groups of

teachers was that all teachers in the experienced group had used variants of CCS technology for over two years, while teachers in the test group had experience of one to three months.

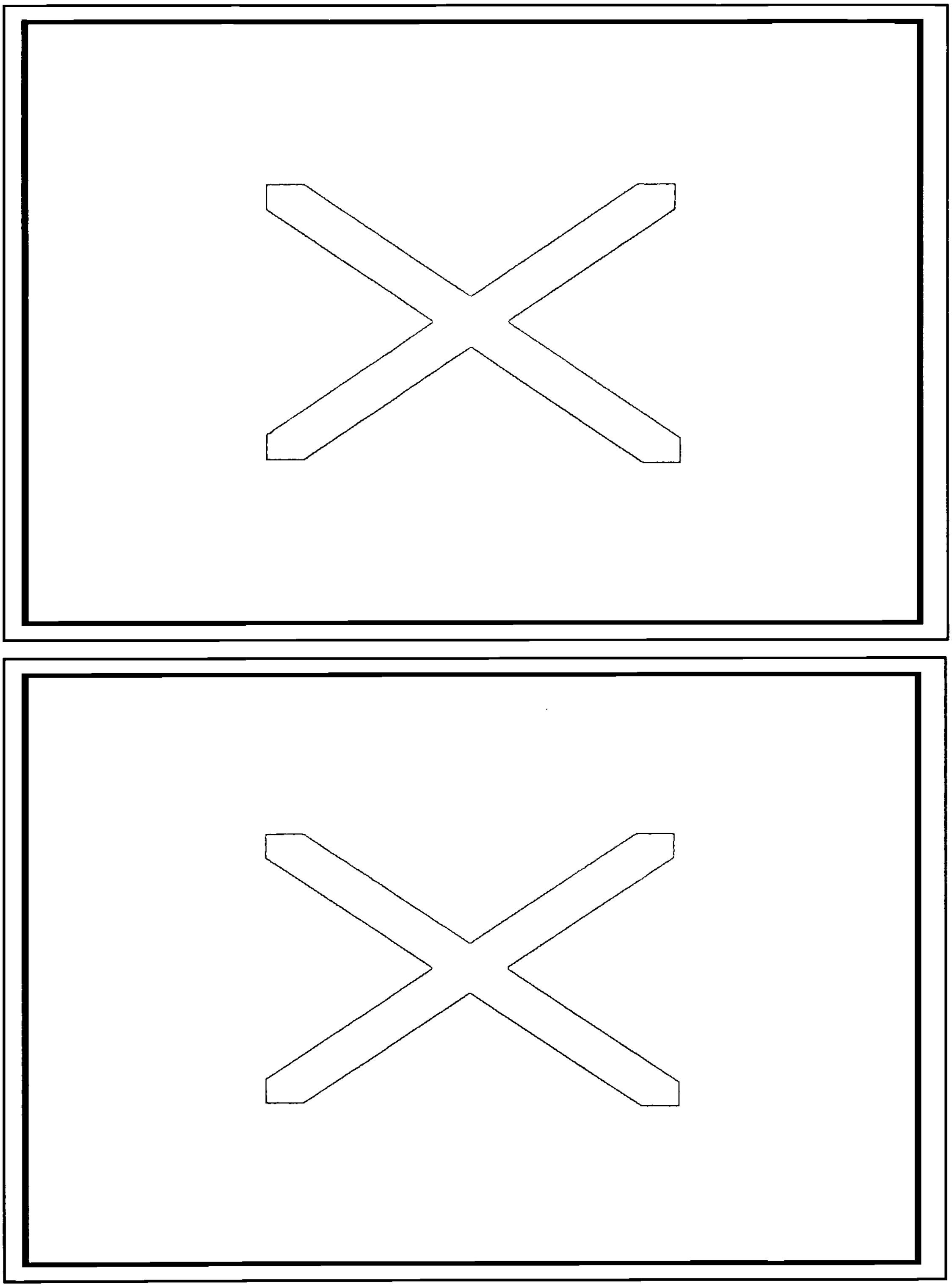


Figure 16. Composite Results from Student Surveys of Classes Taught by Teachers Experienced with CCS Technology Listed in Table 2 Compared with Test-Group Teachers from Table 1

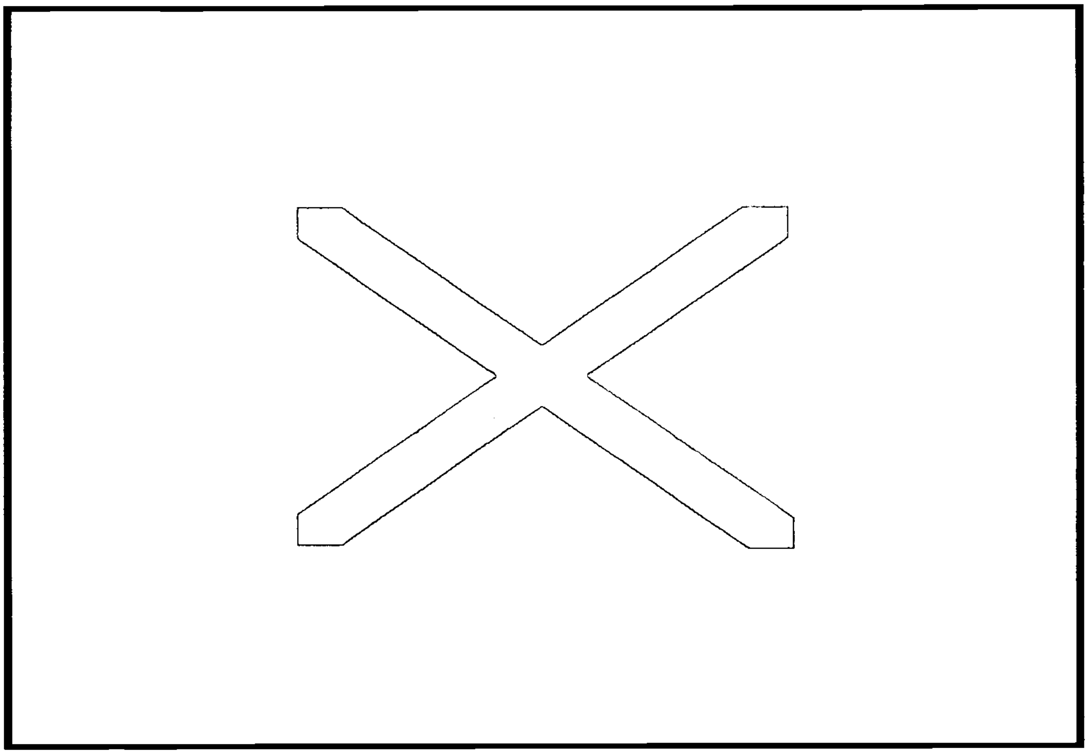


Figure 17. Comparison of Average Student Positions on HPL Centeredness Components from Classes Taught by Test-Group Teachers (Table 1) and Teachers Experienced with CCS Technology (Table 2)

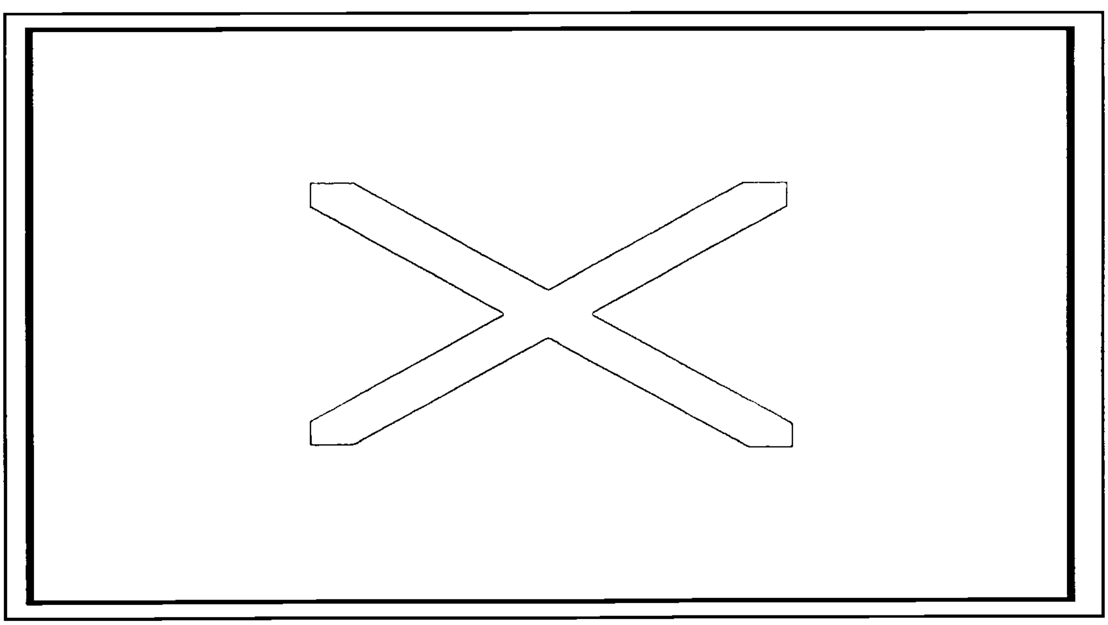


Figure 18. Effect of Teacher Experience with CCS Technology on Increases in HPL Centerednesses in TI-Navigator Classes (from student survey data)

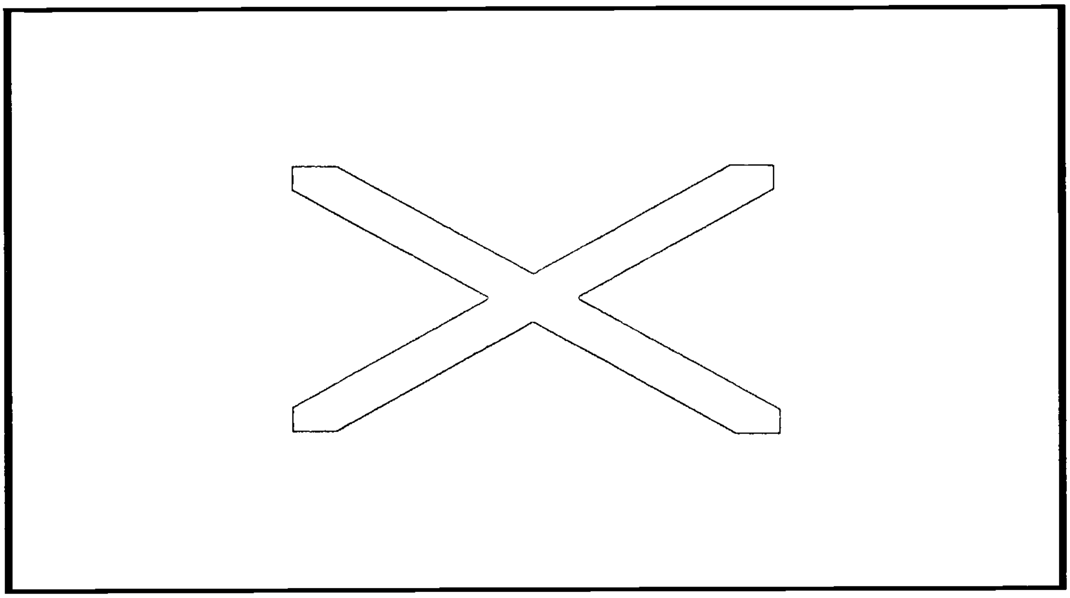


Figure 19. Effect on Increases in HPL Centerednesses from Teacher Experience (from averaged student positions in surveys of classes taught by Test-Group Teachers (Table 1) compared with Teachers Experienced with CCS Technology (Table 2))

The results from Figure 16 are can be summarized by directly comparing the averages of student positions from the new and experienced teacher groups. It may be seen (in Figure 17) that classes taught by teachers who have had longer experience with the technology show significantly higher average positions over all survey components of the HPL centerednesses. These differences are remarkably consistent with gains averaging 206% (+ or – 30%).

The results in Figures 18 show perceived increases in HPL centerednesses derived from summations of the separate component data of these constructs as contained in Figure 16. Also shown in this figure are weighted averaged values of student data using a scale from -2 to +2 (-2 =strongly disagree, -1 = disagree, 0 = neutral, 1 = agree, 2 = strongly agree). These values are plotted in Figure 19, to show comparisons of average perceived increases in each of the HPL Centerednesses for both the test group of teachers and the experienced teachers.

6.4 Conclusions from Comparison of Test-Group with Experienced Teachers

One main obvious conclusion that can be drawn from the results described in this section. That is, the data shows exactly what one would expect if everything was working in the anticipated way (i.e. from prior observations in university physics lecture halls and from intuition). Specifically that,

1) instruments used to measure increases in the HPL centerednesses show do seem to yield data consistent with improvements in these educational environments;
2) teaching does appear to become more effective over time as teachers become more familiar with how to use the technology to improve their teaching; and,

3) subject to more research, it seems reasonable to use the HPL centerednesses as metrics by which to assess better teaching.

7. THE MEANING OF OUR STUDENT SURVEY DATA

Because of the emerging importance of our student survey as an assessment instrument in this research project, it is appropriate to look more deeply at this instrument to determine,

- what it might be purported to be measuring,
- to what degree such measurements are reliable, and
- what is their validity relative to the HPL centerednesses?

7.1 Does the Student Survey Data Give Absolute or Relative Judgements?

First, is the question of whether the survey data are absolute or relative. As can be seen from inspection of the instrument (Section 4.8 & Appendix 2(c)), 9 of the 16 statements are superficially absolute while 7 are overtly relative to other classes or to the same class without TI-Navigator (see Figure 20). The reason for such differences in design of the survey items came from the desire to get at deeper constructs and include shades of meaning. To do this we thought it was essential to avoid making the instrument components appear as a simplistic (and perhaps even repetitious) referendum on TI-Navigator. With this in mind, to express every item in a relative sense would, we felt, lead students to think that we were essentially interested in a "thumbs-up" or "thumbs-down" judgment on the system itself, rather than the subtle attributes that describe an effective learning environment, and which were our real interest.

Nevertheless, in spite of having a split between absolute and relative items in the survey, we believe it is appropriate to make the case that *all* student judgments expressed on completed surveys are likely to have been the result of relative thinking. The reason is simply that, any judgment regarding an educational characteristic of the class that a student is in, can only be made using information from other similar educational situations that the student has experienced. Since none of these other educational situations are likely to have included use of a CCS like the TI-Navigator, it appears reasonable to assume that the "without" case is implicit in every statement.

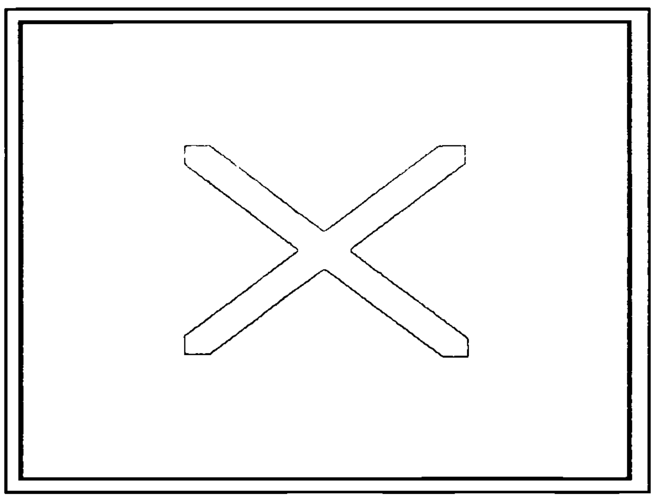


Figure 20. Absolute/Relative Nature of Student Survey Items

7.2 What do Summations or Averages Mean?

Thus, if we do assume that judgments on component statements give data which are relative to other classroom situations, which each individual student has experienced, and put this together with the fact that a summation across students in a class yields the composite strength with which students believe the position to hold in that class, then, what we would be measuring is relative strength of the position compared to other classes (see Fig. 21), which did not use TI-Navigator. Or, possibly the same class before, or imagined without, the use of TI-Navigator.

It seems logical then, to suppose that what we are measuring by adding student responses from these survey questions, are *perceived levels of neutrality, agreement, or disagreement on relative increases of the constructs embodied in the survey items, compared to other educational situations*. Because these are perceived levels, they are inherently subjective., but still we think the data is rightly classifiable as positivistic, because it is derived from a structured survey instrument

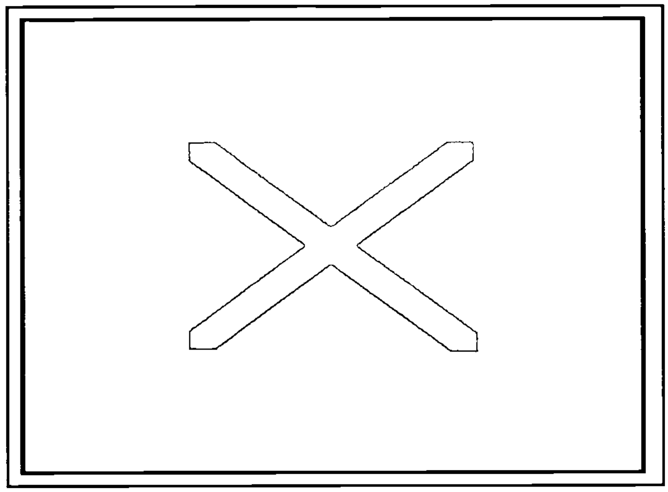


Figure 21. Interpretation of Summations (or Averages)

Thus, it seems apparent that summations of student judgments on individual survey items can validly be interpreted as measuring the perceived strength of increases or decreases, in TI-Navigator classes compared with others, of key constructs on which the survey items are based.

7.3 Reliability of the Instrument

It is common practice when developing a new survey instrument to run statistical checks for internal consistency of the data. However, the usual check of calculating Cronbach's alpha using correlation coefficients between data from pairs of individual survey items, will not work in this case because this procedure is designed for instruments that measure a single (unidimensional) latent construct. In the following section we discuss the multidimensional character of the student survey instrument, and in the subsequent we show how the instrument's reliability can be satisfactorily evaluated.

Correlation Coefficients between Student Survey Items using Raw Data

We would expect multidimensional data because we set out from the beginning to measure eight individual constructs (two for each HPL centeredness). It is informative though, to look at the correlation coefficients between data for different survey items to see how well correlated they are. This data is presented in Table 4, where it can be seen that the inter-item correlation values ("r") range from less than 0.1 to a maximum of 0.58. This indicates that the students' perceptions of the sixteen survey items are such that no pair of items are considered to be the same. However, many pairings of items *are weakly* correlated. That is, there are 16 pairs with absolute values of "r" between 0.3 & 0.4; 7 pairs with "r" between 0.4 & 0.5; and 3 pairs where the absolute value of "r" exceeds 0.5.

It was initially somewhat of a surprise to find that several similar items expressed in the negative sense (e.g. L1 & L-1) were only weakly correlated. However, on reviewing these items, it was obvious that the apparently similar items in fact included many different shades of meaning. For example, C2 and C-2 yield a relatively high inter-item correlation coefficient of –ve .5, but while both refer to a "sense of community" C2 compares this class to other classes, and C-2 talks about "improving" it in the same class. Such an apparently minor distinction of different perspectives could be very important in students' agreement or disagreement with the statements. This was communicated during focus group interviews, where for example, it was explained with regard to C2 that, "this was a math class," and thus inherently inferior for sense of community to subjects such as English and history, so while

someone could agree that use of TI-Navigator could bring math up to the standard of other subjects (showing an increase), they might disagree that even this increased level would necessarily exceed that in other classes (see dialog in Figure 22).

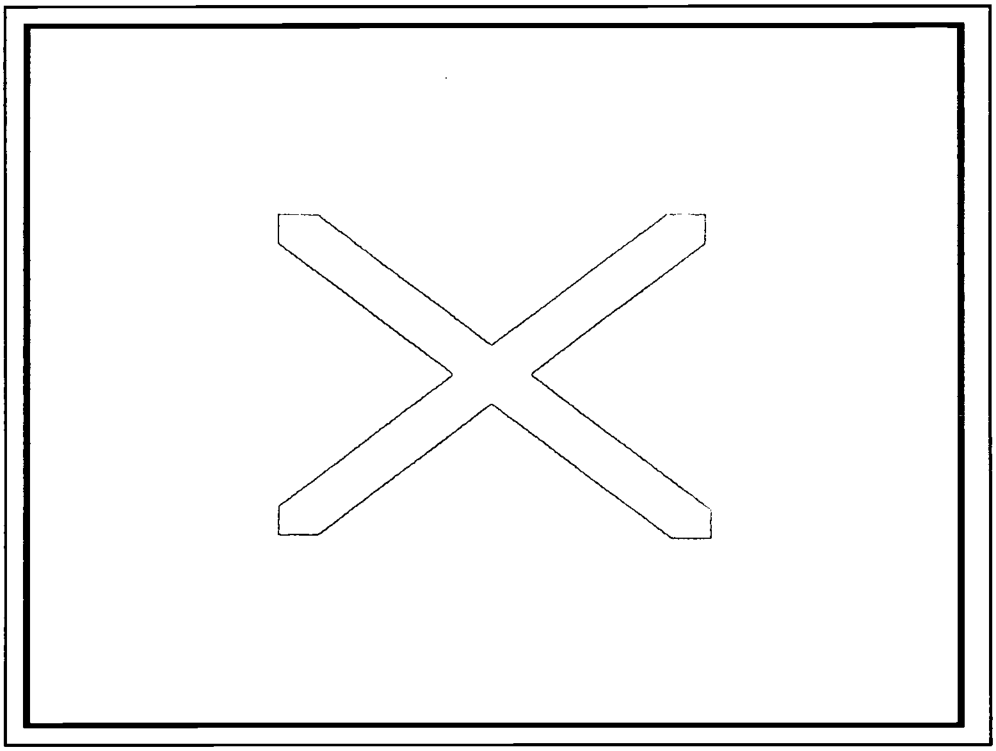
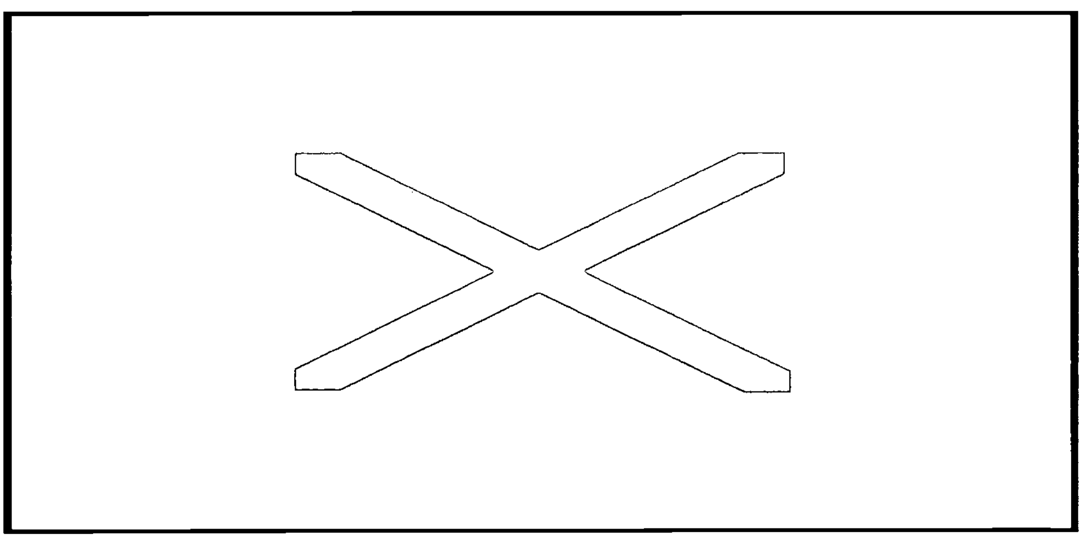


Figure 22. Illustration from Kula 7th Period of Students' Shades of Interpretation of Survey Statements

TABLE 4. Inter-Item Correlation Matrix from Student Survey Data for NEW Teachers (as Listed in Table 1)



In Table 4, the significant number of large off-axis terms might be interpreted as cause for concern, since for example, it is reasonable to think that variables for learner centeredness should correlate better

with other learner centered variables than say with variables for knowledge or community centeredness. However this may not necessarily always be the case. A possible explanation comes from HPL itself where it can be recalled that that the authors depicted the four centerednesses as overlapping circles (see Figure 1), specifically to illustrate their interdependent nature. Thus the data in Table 4 is not inconsistent with the definition of the centeredness constructs themselves.

A clue to the need for a deeper interpretation of the data came from the value of Cronbach's alpha computed using all 16 survey items over all 387 students. This value (0.794)[3] was much higher than would be expected for multidimensional data. Such a value can only result if there is indeed a single latent construct underlying the data. But, we had specifically designed the instrument to avoid it being a simple referendum on TI-Navigator. So, if this is not what we were measuring, what information was the data really telling us?

Correlating between Teachers

Looking at the overall design of the experiment, it is clear that a different approach is needed to compute the reliability of our student survey data. If we ask what the student survey was intended to measure, the answer is, *how the HPL centerednesses changed in teachers' classrooms after they began using the TI-Navigator*. The various items in the survey relate to particular components of this change, but if we compare across all the teachers, we would expect that the changes in the various components would show a pattern. That is, in general, more or less the same things should happen for most of the teachers in their classrooms. It is indeed possible that one or two teachers might be exceptions to the pattern and different from the rest, but since all attended the same preparatory training Institute, it is likely that the results of the remainder would have similar structure (albeit with varying magnitudes).

Thus, if the student survey instrument is internally reliable, one could reasonably expect it to show moderate to high inter-teacher correlations between most pairs of teachers in our teacher test-group. In order to determine these correlations, the average student position for each survey item was computed (see Table 5), across all students in classes taught by each teacher with TI-Navigator.

TABLE 5. Average Values for Each Item on Student Survey for NEW Teachers

[3] Computed using the positively worded statements and inverses of the negatively worded ones.

This data is also depicted graphically in Figure 23, where it can be seen that data from all teachers do follow a similar alternating pattern. The data is also shown graphically for each teacher with accompanying standard deviations in Appendix 5. The alternating pattern evident in Figure 23, is caused by students' general agreement (shown by values > 3) with positively worded statements and their general disagreement (values < 3) with negatively worded statements. The departure from this pattern for item L-2 is due to ambiguous interpretation of the wording of this item as discussed in Appendix 4. We are unsure if the similar departures in L-6 are representative of an actually occurring phenomenon or due to a measurement artifact (see discussion Appendix 4).

TABLE 6. Inter-Teacher Correlation Matrix for NEW Teachers

Inter-teacher correlations were then computed using these average values and are shown in Table 6. It may be seen from the values in Table 6, that the correlation coefficients between all possible pairings of teachers are very high, lying in the range .677 to .930, with a mean of 0.844. Also, the value of Cronbach's alpha obtained using this data, is very high (0.977), which indicates a level of reliability commonly associated only with the best standardized tests. This means that the student survey *does* measures a single latent construct to a very high level of reliability across the entire teacher test-set.

Comparison with Experienced Teachers

As an additional reliability check, the same analysis was performed on data from the experienced teachers (listed in Table 2). Table 7 contains the average values for each item on the student survey for experienced teachers and the inter-teacher correlation matrix between them. Also, Figure 24 shows a graph of the same average values listed in Table 7. It may be seen from Figure 24, that the same alternating pattern exists in the data for experienced teachers as for the new teachers in the teacher test group. The principal difference however, is a much larger amplitude of the alternating cycle for experienced teachers. This can be interpreted as the greater effectiveness of experienced teachers use of this technology, which is being measured by the instrument. (Note: Similar departures from the alternating pattern for Items L-2 and perhaps L-6 are again observed – see discussion Appendix 4.)

It may be seen (Table 7) that the inter-teacher correlation coefficients are more uniform and even higher (ranging from .937 to .981) than the correlation coefficients between the (new) test group teachers (Table 6). This result may possibly be due to the small size of the experienced teacher group, but it is also likely that as the effects being measured become larger, they also naturally tend to become better correlated.

Similarly, the value of Cronbach's alpha for the experienced teacher group is very high (0.985) and exceeds the value obtained for the new teachers. This adds further to our confidence in the reliability of the instrument.

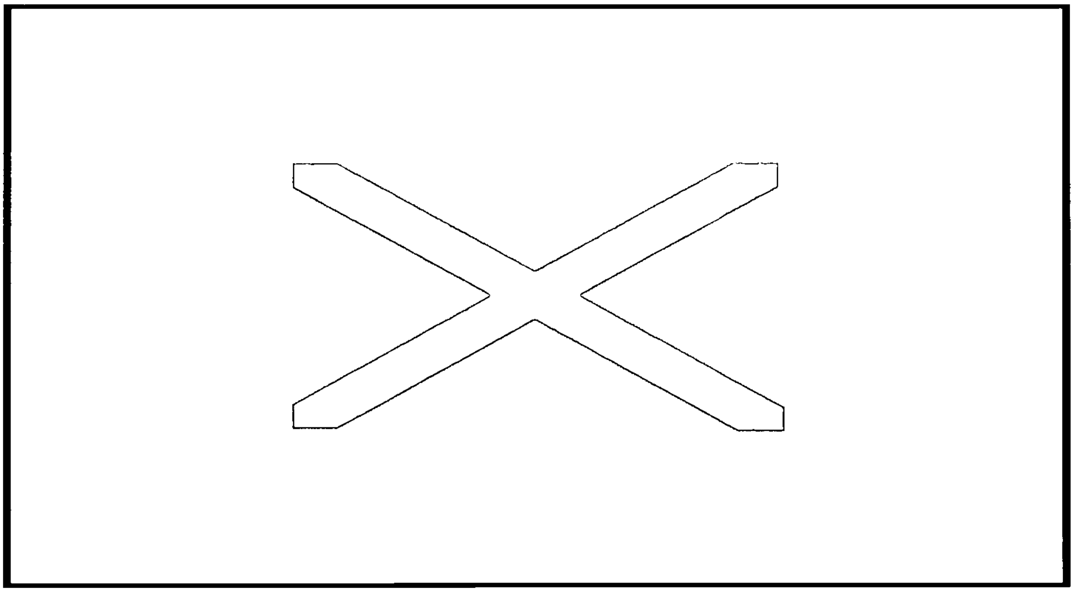


Figure 23. Avg. Positions from Student Surveys (Test-Group Teachers)

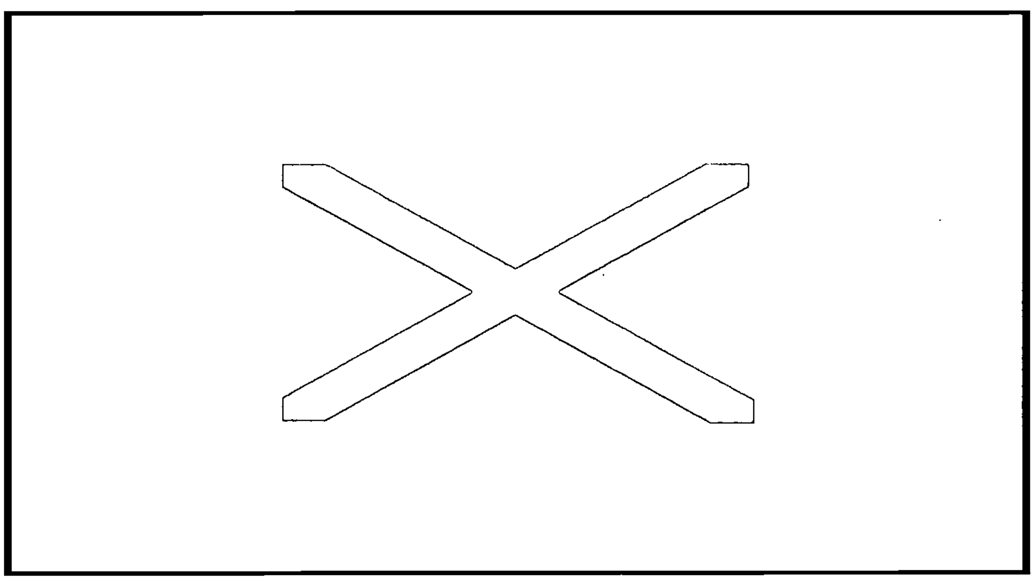


Figure 24. Avg. Positions from Student Surveys (Experienced Teachers)

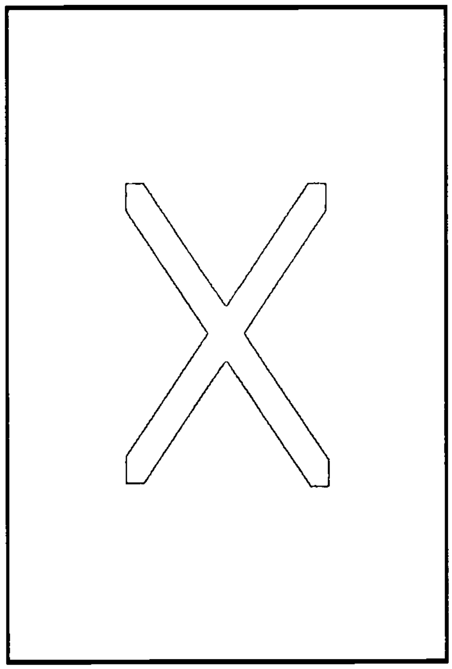
Conclusions from Reliability Analysis

If we consider the conclusions from the reliability analysis in relation to the research goal, the results are very significant. They imply that if we were to repeat the Summer Institute with a new group of teachers, and perform the same classroom assessments using the same student survey, then there is a high likelihood that the results from the new group of teachers would correlate very well with each other, *and* with the results from the first group.

7.3 Validity of the Instrument (in Assessing the HPL Centerednesses)

Suppose that it were possible to make objective measurements of the HPL centerednesses before and at various times after the introduction of TI-Navigator into a classroom. Then one could subtract the baseline and measure differences. In such a circumstance, we could compare the perceived data that we have obtained, with such measurements. What kind of correlation one might expect from such an exercise remains a topic for future research.

TABLE 7. Average Values for Each Item on Student Survey for Experienced Teachers and, Inter-Teacher Correlation Matrix between them.



But, such a comparison is not the only way to gain confidence in data from our student survey instrument. A powerful verifying factor to its validity is the data from the previous section (Section 6) which provided comparisons of results between teachers with long experience in using this technology and teachers with relatively little experience. It was noted that both sets of teachers produced measured increases in all the HPL centerednesses. However, the gains from the experienced group were roughly double those of the group with less experience in using the technology. Note that we were not comparing experienced teachers with novice teachers. Both groups were in general highly experienced motivated teachers. In fact, both groups contained one teacher who was a Presidential Awardee. Yet the differences between these two particular teachers (both taught high school mathematics) were of the same magnitude as with others less publicly celebrated. This data correlated with prior observations of outstanding university physics teachers, where it was observed that it took time to learn the new ways of teaching that this technology facilitated (Abrahamson – unpublished). Thus, the very important result from the previous section's data is that it not only fits well with expectations, but it also greatly adds validity to the student survey as an assessment instrument to measure changes in the HPL centerednesses in test classrooms.

7.4 Relationship to Naturalistic Data

It was never our intention for research in this study, to rely purely on positivistic methods. Indeed, some of the most interesting results emanating from this study have come from the naturalistic approach as shown earlier in Section 5.4 (as described in the following section). The meshing of the two research approaches affords added depth and confidence to results not only showing, "what works," but "how" and "why."

8. UNDERLYING PROCESSES AND MECHANISMS

8.1 From an Dissatisfied Feeling to Deeper Insight

We have shown with some level of confidence, that all four centerednesses (as perceived by teachers and students), increased in the classrooms under consideration, but if the data do not help us to understand more than this fact, then it is surely not worth nearly as much as we hoped for. Actually, the data do provide much more insight, and its source is perhaps a most unlikely place – the words of students themselves. For one of these researchers (Abrahamson), it came as a huge surprise to be sitting in a room with four high school students and have the effects of CCS use in classrooms spelled out in language clearer that he himself had been able to muster after a decade of his own research. This was all the more remarkable because these students had only had the system used in their classes for a mere few weeks.

As the researchers on this project began to swap stories and interview transcriptions, we found that we were all experiencing similar things. It was the students who were telling us how it worked, and why it worked. It remained for us to contextualize what they were saying in the framework of scientific theory, and to correlate it with the perceptions of their teachers. This is the purpose of this section. Also, where appropriate, to clarify and deepen insight into the effects reported, we also include comments from one of the experienced teachers.

8.2 How TI-Navigator Solved a Big Problem for Students

What the students were telling us was that TI-Navigator solved a big problem for them. The root of this problem is expressed in Figure 25 in an extract from one of our student interviews. The dialogue in this figure shows three students explaining their feelings about admitting publicly that they don't understand something in a typical classroom.

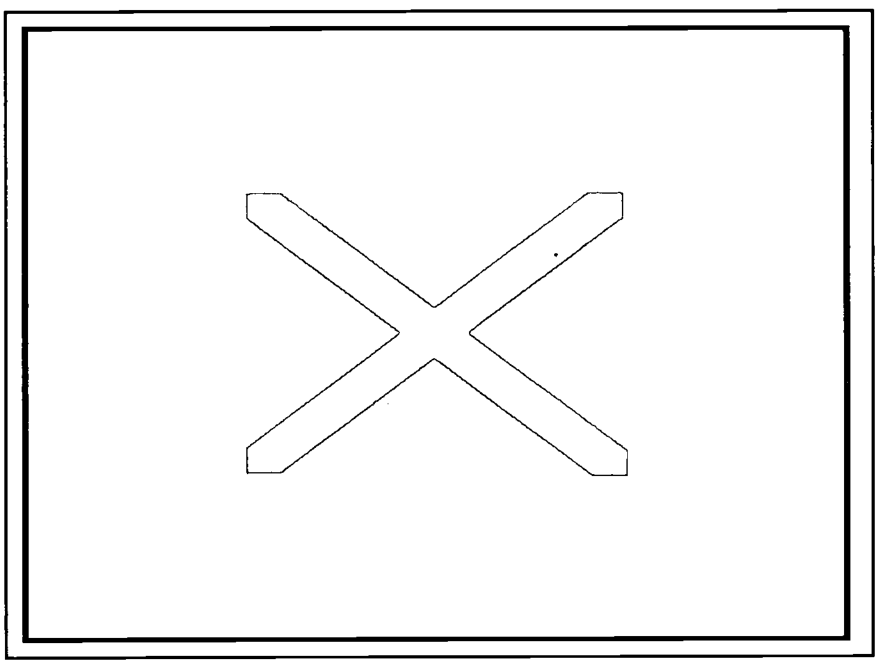


Figure 25. Students Describe Their Reluctance to Act to Solve Their Problems of Understanding in Regular Classrooms

This was a significant interview for us, because it was one of the first conducted in this research program. Also, because the three girls came from the same geometry class, and could not have been

more different. Girl 3 was a quiet and reserved 11th grader, Girl 2 was a super-confident very bright 9th grader, and Girl 1 was a 10th grader. Nevertheless, they *all* felt embarrassed about asking questions in normal classes. What these three girls were saying was that TI-Navigator helped them to avoid such feelings of embarrassment or "feeling dumb" before peers, because it offered them anonymity in critical situations. This can be seen in the conversation that preceded that in Figure 25 as shown in Figure 26:

As we conducted more interviews with students, we found that the subject of how TI-Navigator helped in avoiding negative feelings before peers came up in every single group (see another example Fig. 26).

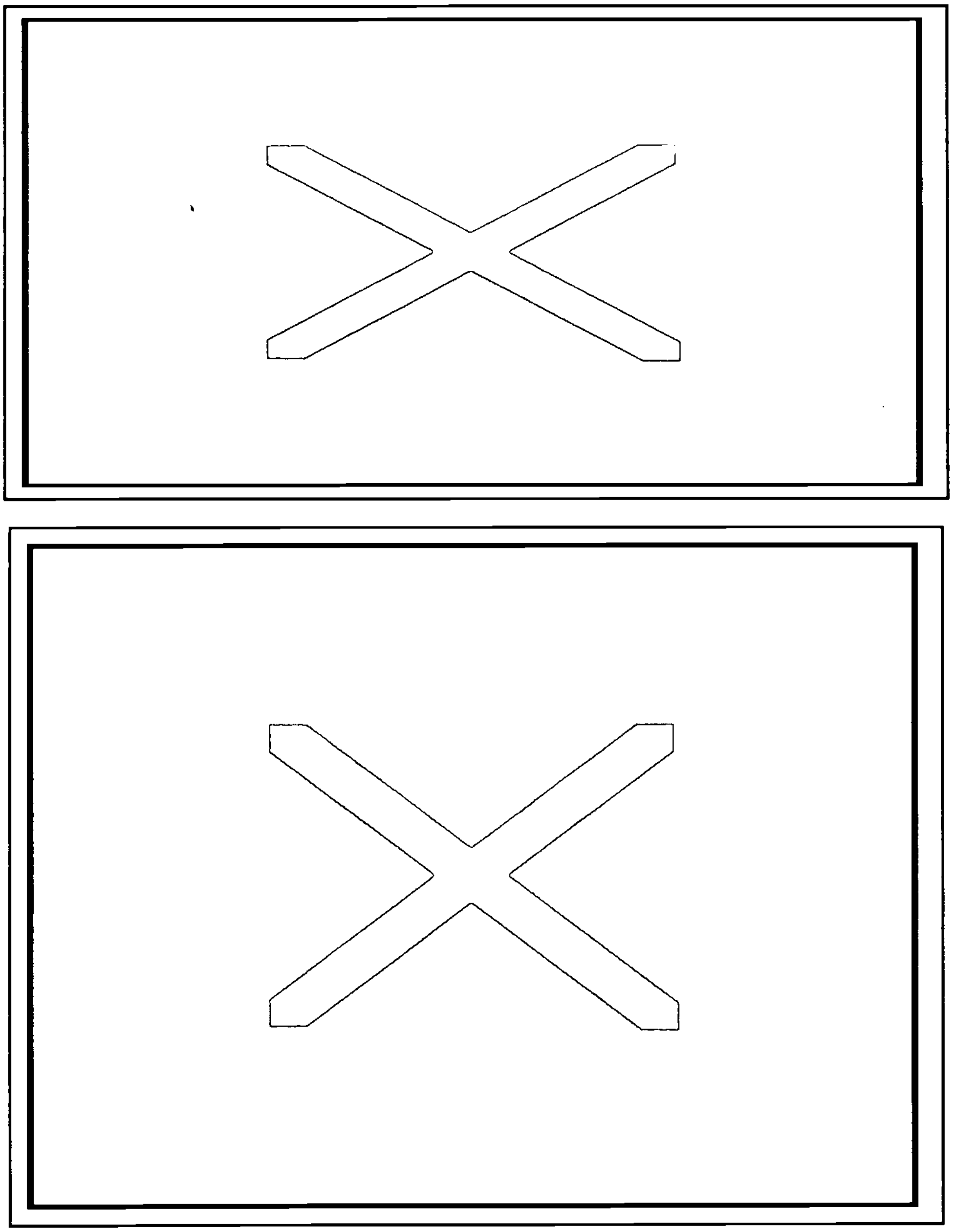


Figure 26. Students Describe How TI-Navigator Helps to Solve Problems by Making Information Public in a Non-Embarrassing Way

But, the students also seemed to be telling us more than, that now - with TI-Navigator, they were able to avoid embarrassment. They were also articulating that in a very fundamental way they were more easily able to express reasons "why" –for better or worse- they held the opinions that they did. They were also telling us that bringing these reasons out into the open, helped not only their learning, but also the learning of the rest of the class. Figure 27 contains a remarkably articulate exposition of this issue, and how it worked for them.

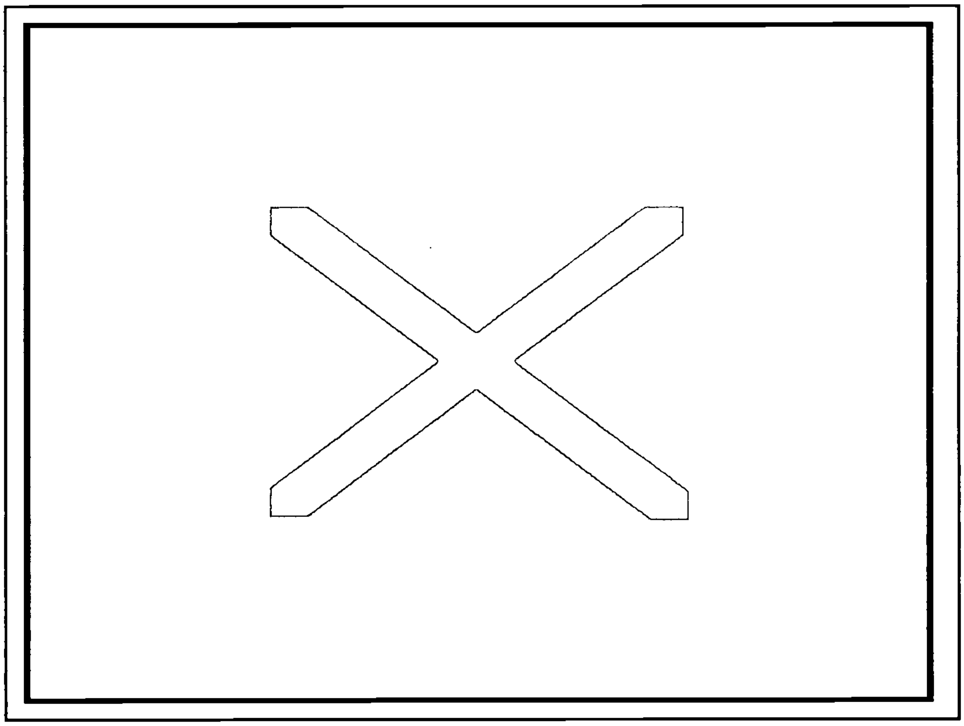


Figure 27. Students Describe How Information Made Public with TI-Navigator Helps to Change the Classroom Climate from Fear of Embarrassment to Constructive Action

Of course, if we had been listening carefully, we would have found the teachers were saying almost exactly the same things as the students, about the effects of TI-Navigator, as seen in the excerpts from five teacher interviews below[4]:

Kula: Navigator allows them to tell me their response without them feeling worried about what everybody else is going to think about them, ... and, it's not so much that they worry about ... having the wrong answer, they just don't want to be the *first* one to say the wrong answer.

Small: ... students will give me a more honest opinion of what they're knowing ... they can put an answer up and not feel ashamed, ... sometimes it's embarrassing for them, or they'll just say they don't know.

Boby: You get more honest answers by using the Navigator. ...And it is anonymous so it's not threatening. It's not like they have to be embarrassed.

Suarez: I think that they notice more with the Navigator because it's very easy to display how the kids answer. And in an anonymous way where the kids don't feel like you're picking on them.

Verde: Navigator gives ... kids who are afraid to make a mistake, kids who are not vocal, who don't want to participate because at this age they're embarrassed at any little thing. They might

[4] Although, the additional part that the students could convey better was how they felt, and this helped us.

have a hair out of place and everyone will look at them if they answer. They are not afraid to answer because they know that only I know they know if they got it right.

Some of the test-group teachers also tended to feel that the significance of this effect was limited to shy students. For example,

Ellis: So being anonymous isn't as critical as you might think among the kids, but yet I think it can play a role in some of the real shy kids.

But, this conclusion is belied by the following anecdote from one of the teachers who had longer experience with CCS technology:

Davidian: This was a real surprise to me! This is a girl, she's a senior, she's taking BC Calculus, she's very bright, she's like something, ... secretary of the Senior Class, she's an elected officer of the Senior Class, she's in the Honor society, she's an elected officer of the Honor Society, she's a Cheerleader, she's tall, blonde, gorgeous, ... um, has boyfriends galore, ... girlfriends galore, um, does very well in all her classes so in my opinion if anybody should be self-secure it should be her. ... but her answer surprised me. She was saying, "One of the things she really liked about Navigator is you really know how you fit in and where you fit in with the class. Some classes you go in and you don't want to ask a question because you feel stupid, because you're the only one that got it wrong, but here you'll know that other people got it wrong, so I don't have to feel stupid, and then if you got it right then you feel really good because you got it right. Um, and you know where you fit in and it's not so bad. Today I got a question wrong that nobody else got wrong, but maybe tomorrow I'm the only one that got it right. Um, no other class does that happen in." And again, the response didn't surprise me as much as the person from whom the response was coming from because she's a pretty together young lady, and if she's feeling that way, what about the students who are obviously insecure.

8.3 What Can Go Wrong in Regular Classrooms

We realize that classrooms are complex environments and there is no universal simple cause for things that can go wrong. But, there is one sequence of events (see Figure 28) that every teacher will recognize as an endemic problem and one that is very difficult to rectify. This problem begins with a student realizing that he or she does not understand something. It might be something that has just been taught or it might also be related to material that was covered at a prior time, perhaps yesterday, last week, or even last month. At this point the information exists only in the student's head, and it is likely to generate two different categories of thoughts. On the one hand, thoughts like,

"I should ask the teacher or do something else about it,"

and on the other contrary ones like,

"I don't know what (or how) to ask," or
"Other students will think I'm stupid, " and,
"Maybe, I'm the only one having problems!"

Using Kant's division of the mind into three parts (cognitive, conative, and feelings), the result is likely to be internal conflict. The original realization of the existence of a problem is cognitive, the urge to do something to solve it is conative, and the elements of personal risk generate feelings which oppose the conative urge (see Figure 28). There are two possible outcomes, either,

- the student will overcome the negative feelings and act to solve the problem, or
- he/she will be intimidated and do nothing.

Once the second option is chosen the likely possibility is that the student will slip behind, and the teacher might not know until the test, when it is likely to be too late.

The result of this apparently common classroom pathology, is that learning doesn't happen, and the student is likely to continue into the rest of the course and possibly into higher level courses, still not understanding. This can be like a process of building even more structure on top of a weakened foundation, with the risk that the entire structure will collapse, and the student will drop out of the discipline. Even if it does not collapse and the student continues in the discipline, his or her ability to benefit from the knowledge can be impaired because critical understanding of concepts needed to transfer and use the information is missing. These are devastating consequences for a seemingly trivial cause.

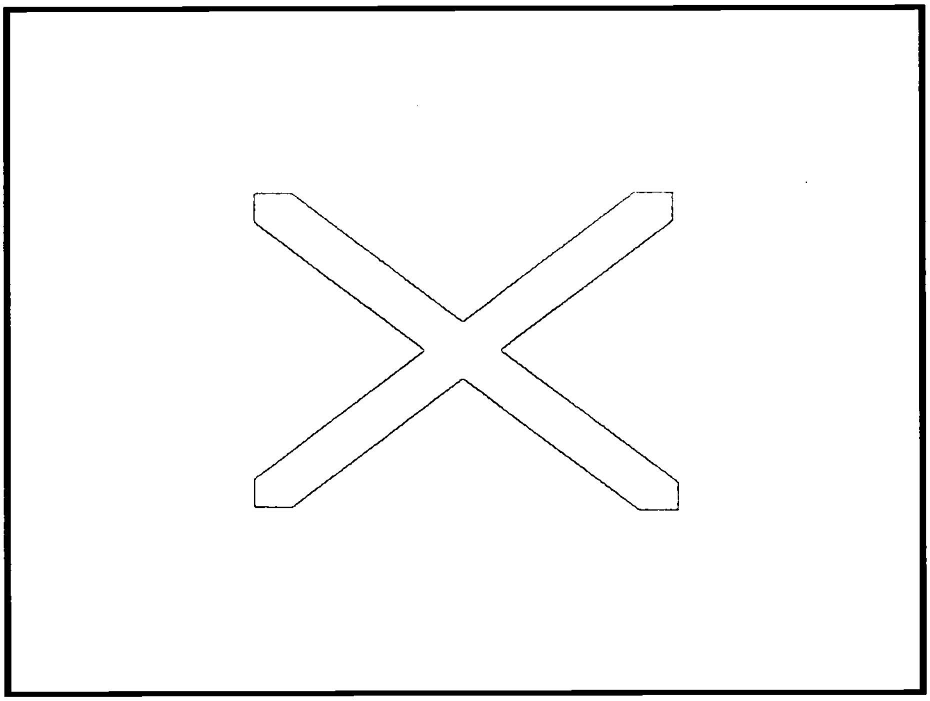


Figure 28. Graphical Depiction of a Common Classroom Pathology

8.4 Hypothetical Curve of Processes Following CCS Introduction

We preface the discussion by stating that clearly much more research is needed in this area because what we are about to describe does not come from longitudinal observations. Rather, it is the result of conclusions from information pieced together after the actual events have taken place. The sources for the information are student interviews from the focus group sessions in this research project. We also include some references to teacher interviews performed in this same study.

Personal Privacy & Anonymous Feedback

In the previous pages we described what seem to be the key factors in CCS classrooms, that initiate a beneficial sequence of events to solve a common pathology. These are "personal privacy" and anonymous feedback on positions. They are shown as the first two points on a hypothetical curve of "Sense of Community" versus Time following the introduction of a CCS into a classroom (see Figure 29). Personal privacy for every student comes from the fact that a well designed CCS does not allow students to know what other individuals have done in executing any activity unless that person voluntarily shares the information. The teacher knows what every student has done, but this information is displayed on a private monitor for the teacher only. Thus, the fear of embarrassment is instantaneously removed from students, and the teacher gains the ability to provide feedback without publicly identifying a particular student.

Knowledge of Class Positions & Realization Others Have the Same Difficulties

The next thing that happens is that students see class data displayed in an anonymous format on the public display. This enables every student to have knowledge of the positions taken by the entire class in doing the activity. At this point a very interesting process starts to take place. See for example, Figure 26, where two groups explain what happens: *students begin to realize that they are not the only one having difficulties*. Even more, it is clear that others are likely *having the same difficulties* as themselves. These two realizations are obvious to any teacher, but they can be seismic events for students. Over time, they can remove a great load of secret fear from individual students, with the result that the classroom becomes a safer place for discussion.

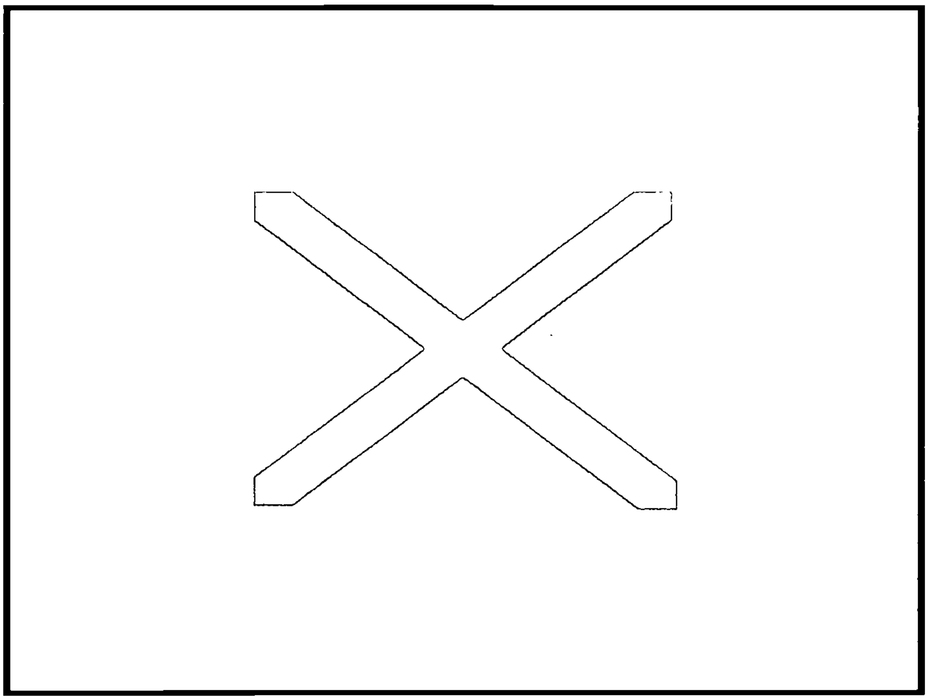


Figure 29. Hypothetical Curve of Processes Following CCS Introduction into a Classroom

Most teachers are well aware of the issue, but it is not easy for them to solve, and they feel that the great thing about Navigator is that it solves it for them in a very natural way:

> **Kula:** They can *see* that ... others don't necessarily understand it at the same time they don't understand it, and they're not the only one, and even if I'm polling the class without Navigator the ones that are more ready to respond are the ones that get it, and the ones that don't are sitting there thinking, "Gee everybody says they get it and I don't ... !!" ... And, they think they're very alone in that boat ... and they've *(laughs)* got a lot of company!!

However, it can also be difficult for teachers to imagine the degree of distress and loneliness that their failure to understand, causes some students. For example,

> **Driscoll:** He came to me separately and also in class word got back, "I don't feel so stupid because other students were giving answers!" - and this was mind-boggling because it was the first time he'd experienced the fact that he wasn't – the only one not getting the answer. It surprises me. It still surprises me to this day!

Even teachers with longer experience of CCS technology, can be surprised how classes new to Navigator can act to hide their difficulties:

Davidian: I asked if there were, "Any questions?" No questions! "Everybody understands?" Yes! "Everybody understood, anybody have any problems?" Nobody had any problems. I just had an inkling that they really didn't understand what they thought they understood, so I logged onto Navigator and put in some kind of an activity where it's, … "Write an equation with the y-coordinates twice the x-coordinates," and I put in the correct answer "y" being "2x," and the kids would type in their own answers and each child gets an individual score I get everybody's scores as well as everybody's answers, correct or incorrect. And um, I was really surprised how ***many*** kids got the question wrong. I knew some of them were having trouble so I knew *all* of them weren't okay with it, but I didn't realize how many of them did not understand the concept. And so, at that point it was clear, not only to me but also to *them*. It was like, "Look at this!!" *(laughs)*, "This is something we need to go over again!" … I never would have been able to figure that out. I knew some of them didn't, but I didn't realize it was to the ... *extent* that it turned out to be.

Class Discussion & Reasons for Actions Taken

The realization that others are having the same difficulties turns out to be a powerful catalyst for interaction in a classroom. Quickly students seem gain the confidence, start asking more questions as shown in Figure30, and being more frank about their difficulties, as shown in the next point on the curve in Figure 29, which is more "class discussion." The next stage happens when the reasons for actions taken are given, then students can see that it is the reasoning that is important – not simply being right or wrong as in Figure 31 when "David" & "Melanie" talk about *"explaining the answer."*

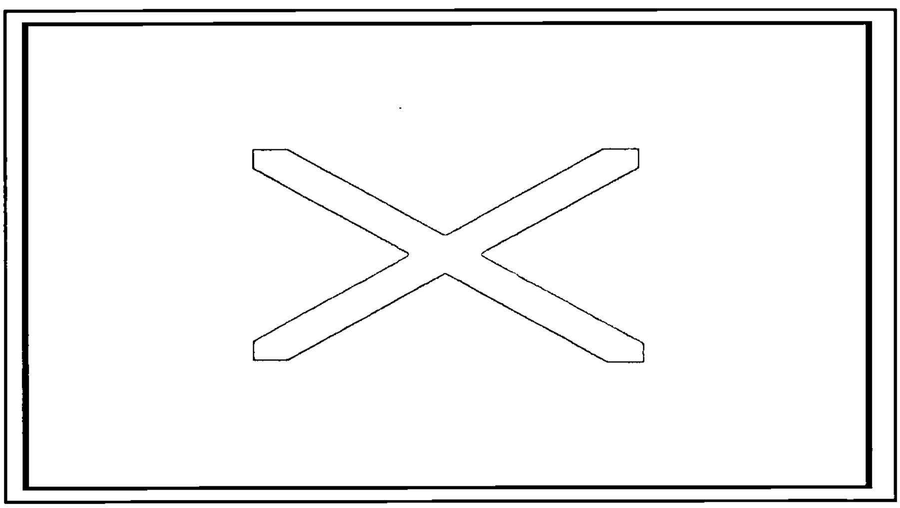


Figure 30. First Steps in Evolution of Community Centeredness

Their teacher had similar but more articulate comments, about what was occurring in his classroom:

Small: Again, I refer to the little impromptu debate that occurred yesterday. You know the best way to learn is ironically to teach. And, when you see students engaged in arguments over whether one answer is correct or not, it's exciting to see because that's a true form of learning. You know, even if you can defend the wrong answer, you have to know something. And too often in education, I think we expect there to be only one answer, and we expect students to regurgitate facts. What I've enjoyed about the Navigator, is that it elicits active participation,

communication, argument, debate, processing among the students: um, often on their own *impetus*, nothing initiated by myself.

Other teachers particularly noticed the impact of this process on students who did not normally participate actively in class interactions. For example,

Suarez: I think that what the Navigator has done is it's brought other kids to the forefront. Other kids that normally would not lead the class or help in the class because a lot of them don't traditionally, the kids that don't usually do well in mathematics really do well with the Navigator and the technology and then become leaders in the class.

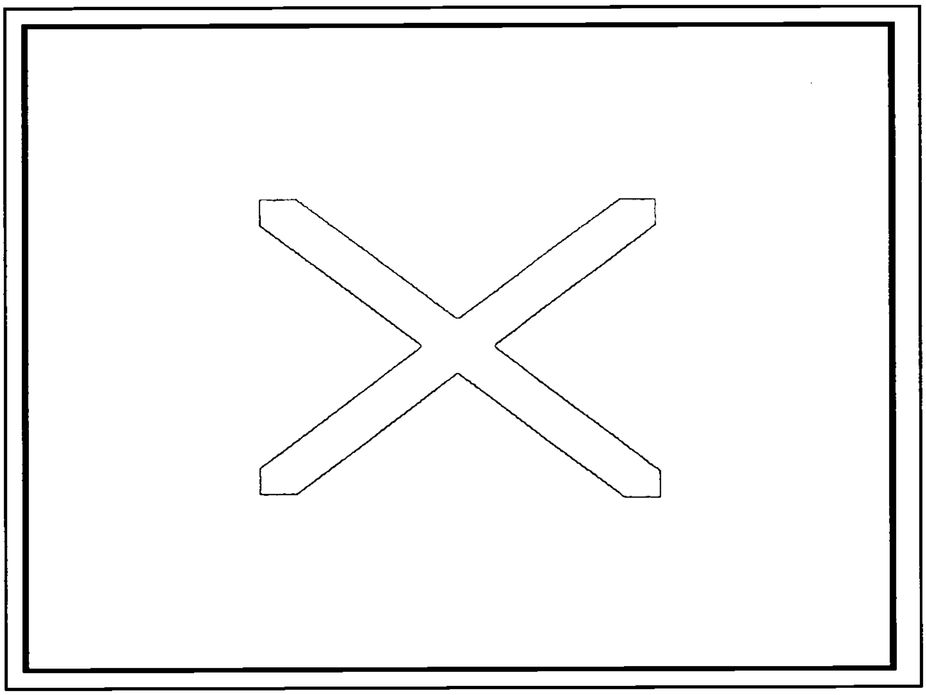


Figure 31. Next steps, "It's about more than right or wrong!"

But, this does not mean that the atmosphere in the class becomes a "free for all." Teachers particularly noted that the focused discussion actually prevented this from happening. For example,

Ellis: Another way of looking at that issue is a system like this prevents the extrovert from taking over.

Int: Ah yes, right. That's the other side of the coin.

Ellis: Yes, as a teacher all you need is 1,2 kids who are too vocal and too loud and their hands are always up and they're shouting the answer out and that can disrupt what's going on in the classroom and intimidate the shy kids.

And, this tends to be echoed by the students:

Girl 1: ... because usually I'm not that real talkative in class ....but I try not to be *(laughs)* ... , or if I'm talkative I talk about a lot of other things than math, but with the Navigator you have to focus on it or you miss everything. (Kula 7).

Lack of Embarrassment & Peer Interaction

The longer that this increasingly healthy atmosphere persists in the classroom the more likely it is that embarrassment declines. For example (as shown in Figure 27), students become ready to argue for their position, even if they are the "only one" who is taking that position. As "Boy 1" (Fig. 27) explains, that he would not be embarrassed because "... *there's other people out there that think the same way*

you do and they'll benefit from you asking the question." The transformation to this attitude from one of conflicted silence as depicted in Figures 25 and 28, is highly significant. The resulting peer interaction is valuable because, students having just learned something, may well be better able to explain it to their peers that the teacher, who learned it so long ago, that he or she has likely forgotten the conceptual difficulties that they had when they learned it. One teacher illustrated this in the following excerpt:

> **Davidian:** When the TI people were here asking questions she made a contribution and she said, um, "When you know you got it right it's really easy to explain what you did!" and um, that was interesting and it gets people, … . Mary will start explaining something and Johnny who now also got it right and knows there are only two of them that got it right will kind of jump in and help Mary explain sometimes.

Also, the act of explaining something to a peer enormously helps to clarify ones own ideas of how the item under discussion works.

Another benefit that emerges from such classroom interaction is associated with human needs for companionship and society. That is, as the classroom becomes more community centered, this fact can be reassuring and highly satisfying in itself (see for example Figures 32 & 33).

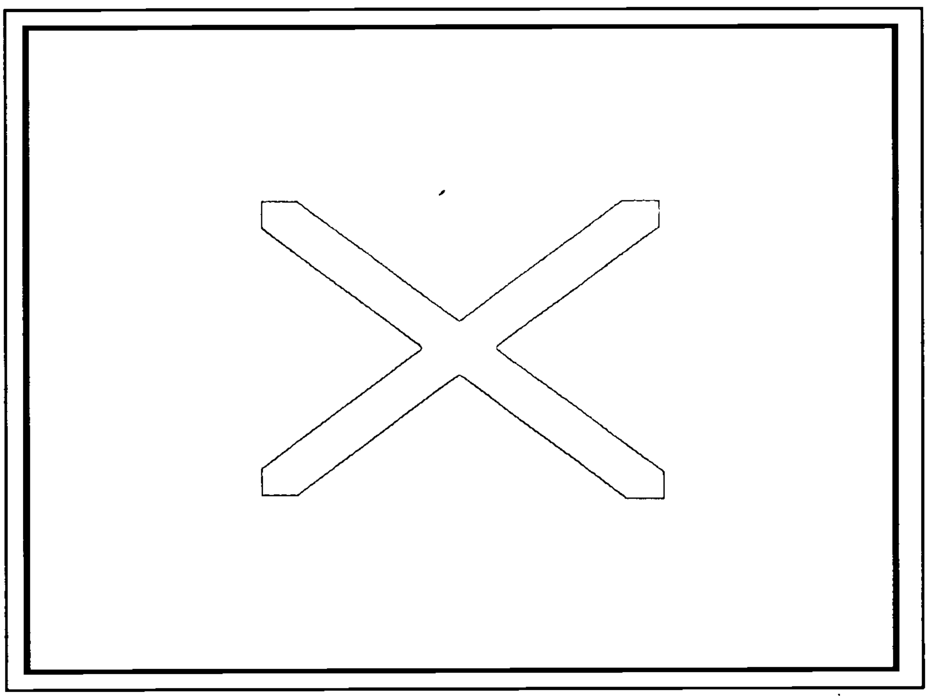


Figure 32. Steps in Evolution of Community Centeredness ("Peer Interaction & Less Embarrassment")

The teachers noticed more peer interaction and believed that it was having a positive effect on their students' learning, as seen in the following excerpts:

> **Hirsch:** Then they'll ask or, if it's an activity that will let them go back, they'll go back to try and get it right. They'll try to figure out why they got it wrong. So to me, that kind of gets them more into that level of thinking, "What was it that I did wrong?" instead of just kind of glazing over the fact that, "Oh! It's not correct and I don't want to ask about it."

Kula: The connection is not just the plugging into the hub, they're .... they really seem connected. They're much more ready to, "Okay, let's do this one and let's figure it out," and I have to be if I really want them to answer totally by themselves. Um, I have to be very firm about it because it seems to draw them into, "Let's talk to each other. Put this in!!"

Small: When you do that kind of learning, it's because you want to! You don't get in a discussion with someone, because you have to. You get in a discussion with someone, because you want to, ... and when students want to do something, they learn. ... When you have that interaction, you get a far, at least I feel, that you get a far better, ... a superior level of learning, taking place.

Suarez: Uh - I think again it's the dynamic interaction that they have with the different activities, ... being able to give all the kids different problems where they could help each other with the concept, but not give each other the answers. ... today you saw some of the kids get up and move around and go help others, ... the ones that got up and helped aren't always the straight A students, which is really cool. ... What was interesting - it seems to be happening a little bit that if someone was doing better it wasn't that they wanted to get that other person's numbers for the "M" and the "B," it was like a motivation that, "Oh, I can do even better with the line!!" that was kind of interesting, that dynamic there.

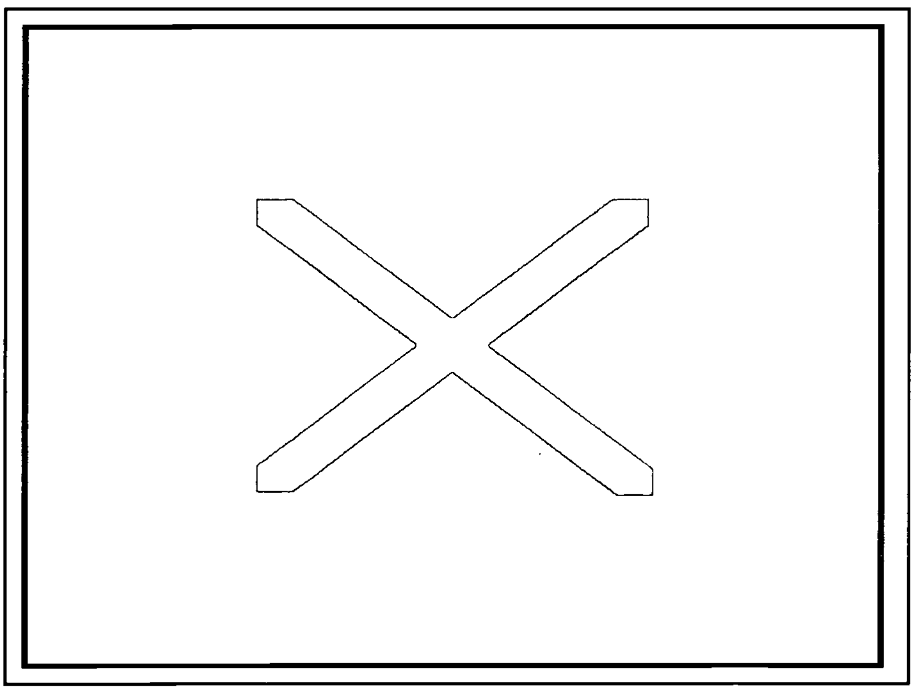


Figure 33. More Steps in Evolution of Community Centeredness ("interaction & giving reasons why")

Non-Confrontational Competition, Cheering & Enthusiasm

There is no doubt that TI-Navigator tends to promote a competitive spirit in the classroom, but strangely enough, it is competition of a very non-confrontational nature. Also, it seems to be of the sort that strengthens, rather than reduces, bonds between students. This type of competition is multi-dimensional in nature and we do not pretend to be able to describe it fully here. Rather, we will simply

try to describe some of its most clearly evident characteristics. We've noticed that it sometimes takes the form of a good-natured challenge to do better, with at the same time, a spoken or implied offer to help the person to whom it is directed to make it happen. But, these sentiments are better expressed in the words of the students and teacher themselves. First, an 8th grader (from Suarez & Verde's classes):

Luis: We don't do it as in conflict. We do it as we want to do better. Like we told her, like if they're close to the line, we can tell what number you put there. We can find it closer and closer. ... Because, it's like we help each other but then again we're happy for each other. Like if you get first place, then, "How'd you get it? Let me know! I want to know ... I want to get a good grade too!"

Next, two of the teachers:

Small: ... it's almost a competitive nature in a strange sense that they want to see how they perform, and they want to understand why they missed it. If they see that half the class got it and they didn't or they were in the minority. I saw that yesterday with several students, ... I don't think that it makes a massive difference, but I think there are people that are reached there that wouldn't normally be reached.

Suarez: ... some kids have success and the other kids, "Oh, if he can do it, I can do it," and then they try harder,

The result is something that one of these researchers (Abrahamson), has often witnessed situations in classrooms where students will cheer if the whole class does well, especially if it is on a problem that they (as a class) have struggled to master. The following two teachers explain:

Davidian: ... all working together as a group and all being involved and they feed off of each other, and you know, it's, "Wow guys look at that, we did this, we did that!"

Hirsch: You know I've talked about that, that I like the fact that the kids get excited if they got 100%, "I got 'em all right!" or the kids that don't are like, "Ohh, what did I do wrong?"

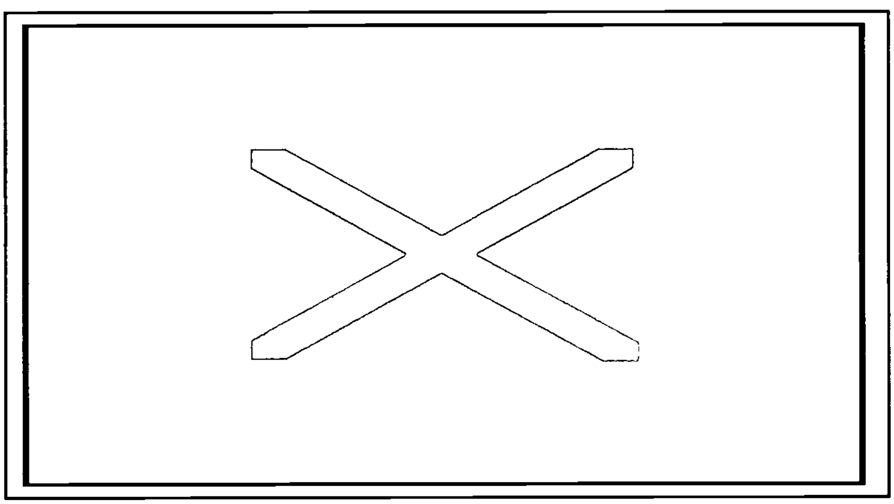


Figure 34.

The fact that students enjoy the type of competition prevalent in Navigator classrooms is illustrated by the first comment in Figure 34. Also, there is another dimension completely because Navigator is also well suited to an extraordinarily wide repertoire of games. These games have learning as their goal, and they range from the simple to the highly complex. The second set of comments in Figure 34 relate to an example of the former, and it can be seen that even simple games seem to generate significant enthusiasm in classrooms. In the latter category, the best known are "Participatory Simulations," where each member of the entire class participates actively in controlling some aspect of a simulation. These

have been developed under NSF funding (Wilenski & Stroup (2000)), and are aimed at raising the bar for this genre of classroom activity to a whole new level.

The following extract from Ann Davidian's interview, describes how her class responded to one of these participatory simulations known as "Gridlock." The activity relates to an inner city traffic-light network in the "City of Gridlock." The Mayor of the city has a terrible problem with traffic flow, and the class has to try to solve it for him. Each student controls one traffic light shown on the computer projection of the inner city roads, and the class beginning with trial and error, has ultimately to figure out the algorithm that will get the simulated traffic flowing smoothly. As Davidian intimates, roomfuls of Ph.D.s have had significant difficulty with this problem. But, her graduating AP calculus class was different, and exhibited a cohesion that solved the problem more easily than their more elevated superiors:

Davidian: I said, after the AP [exam] we're gonna do another fun one, so we did "Gridlock," and it was just amazing. I've seen "Gridlock" done. ... I've participated in "Gridlock" at conferences with strangers and it was a disaster, with everybody crashing into everybody, etc. etc.. And, it was interesting in my class because it was all, ... they talked to each other, and they listened to each other, and that's come from having done this all year long, and Navigator has done that, in the way I explained it before, but it's followed through in even fun activities. So, the class has become a community and it's established itself and its not dependent on anything other than now with, "That's just the way they are!"

According to Davidian's description, the key to her class's success in this type of competitive situation seems to have been due to their ability to work together as a team. She also states that, in her opinion, this ability was due to their experience, over the class year, with TI-Navigator. This model of class collaboration is an interesting result, given the fact that the nation's high schools are often divided many ways in exclusionary cliques and groups.

Same Side as Teacher

As we come to the final points on the curve of community centeredness versus time shown in Figure 29, it should be clearly stated that our evidence at these levels is becoming thinner. That is, we believe that there was not sufficient time for most of our test-group teachers to reach the points where these type of effects would have become clearly evident. Thus, most of our data here comes from the one experienced teacher who we were able to interview under the scope of this project.

However we think it fitting to begin with a comment by a student of the test-group teacher with longest system usage. This student of Driscoll's said:

Girl: We're all kind of in the same boat!

... by which she meant, " ... all the students in the class *and* the teacher." Although, this student was having trouble expressing her thoughts, and had prefaced her remark with the statement, "I don't expect you all to get this!" we believe that it was a very insightful statement on one of the major effects of longer term usage of a system like TI-Navigator. We go to Ann Davidian to explain:

Int: Does it also change the dynamics between you and the kids?

Davidian: Yeah, because it, ... it's in the sense that we're all looking at it together for the first time so it's not that, "I've graded them," and, "I know what they've done," and, "I'm giving it back," and, "I'm going over it." With Navigator, we're basically all seeing the information *together* for the first time, and that

> ... it does, ... it's hard to explain how it does it, but it's like, "Oh well, look at that, this is something I need to go over ... -- " or, "This is something!!!"...
>
> Or, I'll start by introducing a question and I'll start by saying, "This question's a little bit difficult!" and I'll see everybody got it right, um, and I'll go, "Oh wow! That's really neat that you guys all got it right!"
>
> Or, a question that I think is basically simple or straightforward that a bunch of them got it wrong, so it's like, "Wow! See, I thought that was an easy question!" "How come it's not easy??"
>
> So, we're more, I guess we're more united also in that sense. That it's not me, I go in, when I'm checking homework, I go in with preconceived notions of what questions are gonna be easy and it doesn't work out that way. And um, so we're kind of exploring concepts and ideas together.

Essentially, what Ann is expressing here is the same sentiment that Driscoll's student was also saying. Namely, that the students and the teacher have been transformed from being on opposing sides, to being on the same side. This would be a very significant relational change, if it were generally perceived in this way by students. Since we did not interview any of the "experienced" teachers students, we do not have direct evidence in this regard. However, the following description of an event by Ann Davidian, speaks powerfully to the likelihood that this is indeed the case:

> **Davidian:** It's interesting after my AP calculus exam, we do a bunch of different projects, and um, and one project we do is the kids prepare a PowerPoint presentation on advice to incoming AP calculus students. It's meant to be fun, and they poke fun at me, and the class and everything else, and they warn them all different things. This year, I think about 3 or 4 groups out of 9, - I haven't seen them all yet - but commented on basically, "If you're only gonna do homework in *one* class, you have to do it in this class!" ... because, "Navigator is watching!!" and Navigator is this and Navigator is that. Um, so it wasn't, ... their advice wasn't that, "I'm gonna get them, but that Navigator's gonna get them," basically.

Finally, a comment by Derrick Driscoll:

> **Driscoll:** I see a much more understanding community of students. Not only them of each other, but them of me and me of them.

Pride in Class Achievement, and Increased Community Centeredness

It is not our intention here to present direct evidence on the issue of "Pride in Class Achievement." Rather, we feel that this result can be detected by a careful "reading between the lines" of the weight of evidence that we have presented in this section. Also, it is our sense that this is the likely outcome of the cumulative effects which we have been describing, because in some respects it is synonymous with community centeredness, whose evolution in CCS classrooms has been the major topic of this section. However, as with all topics presented in this Section, there is need for much more research.

8.5 Links with Theories Related to Human Motivation

When, we began feeling our way around the reasons, that our data was showing increased HPL centerednesses in the test-group classrooms, it came as bright light to realize that the processes we were

detecting seemed to be in concert with some of the best known theories related to human motivation. In fact, the data that we started plotting intuitively on the hypothetical exponential curve (see Figure 29 in the previous Section), correlated so well with the theories that we looked at, that we began to be awed by the potential significance of what we appeared to be finding.

Whether we looked at Mazlow's, hierarchy of needs, self-worth theory, attribution theory, or self-efficacy theory, there were clear links between them and the points on the hypothetical curve that we had drawn. The ways in which these links tie together are described in this section. Clearly, there is much more research needed, but we feel that these correlations hint at perhaps the most fascinating aspect of the entire body of work described in this report.

Coping Theory

First, we return to the impasse in which students seem to find themselves in regular classrooms. We have shown that student actions in classroom situations may appear to be counter-productive to their interests and to their learning (see Figure 28, & Sections 8.1 through 8.3). The question might be asked, "Do human beings really behave like this?" and, "Are so many of us actually capable of actions that seem clearly designed to harm our own long tem interests?" We have presented evidence that the answer to the first question is in the affirmative. As to the second, we have implied that the problem is indeed widespread. However, because this was a limited exploratory study, there is only limited data to back up this notion.

Clearly, much more research is needed. But, we can look to an area of psychology that has come to be known as "Coping Theory," to inform the likelihood that the problem may indeed be widespread. Coping theory helps us to understand stressful situations and how people deal with them. That is, it models the "ability of stress concepts to tie together diverse kinds of environmental demands and human reactions," (Carpenter, 1992). In coping theory, a central tenet is the distinction between "adaptive" and "maladaptive" coping behaviors. These do not depend on a person's ability to control "stressors." Literature on coping is often associated in dealing with death, or fatal diseases such as cancer, and HIV, where the "stressors" are relatively uncontrollable. But, there is also a growing body of work related to coping in less obviously traumatic life events, and also ones where the "stressors" can be seen as more controllable. These include events from infertility, to performance in work or sport5, and also education . See for example, Schwarzer, C. and Zeidner, M. (1996) "Stress, anxiety, and coping in academic settings," . Tubingen: Francke-Verlag. 1996, and "Zeidner , M. & Schleyer, E.. "The effect of educational context on individual difference variables, self-perceptions of giftedness, and school attitudes in gifted adolescents." Journal of Youth and Adolescence, (in press). Currently, the relevance of coping theory to classroom situations is an item that is proving to be a fruitful topic of research, along with other motivation and emotion work in education (Op 't Eynde, Peter, & De Corte, Erik, 2002).

The main results from coping theory that we want to emphasize here, are that our data are far from being in conflict with what is known. That is, coping theory tells us that,

1) maladaptive coping *can* occur,
2) its occurrence is *not* unlikely in stressful situations,
3) coping strategies can be changed, and
4) effective coping can be taught.

[5] For example, Brown et al. (2002) discuss adaptive and maladaptive coping by salesmen following loss of a major sale, and, Rawstorne et al. (1996) coping style following acutely stressful events in competitive sport.

Our data showed maladaptive coping techniques appear to be common in classrooms (see Figure 28, & Sections 8.1 through 8.3), where problems in understanding and fear of unfavorable peer reactions, commonly lead to avoidance and rationalization. We showed that pressures for maladaptive coping are not limited to shy or unsuccessful students, but that they also affect students at the other extreme[6].

In practice, since a CCS tends to ameliorate the stressful situation in the classroom, it could be thought that there might be no further need in this area for coping theory. However, we feel that more work is needed to flesh out ways in which teachers, armed with a CCS, can move whole classrooms of students over the hurdles of problems in understanding, and cope effectively with peer relationships.

Mazlow's Hierarchy of Needs

The next question that we want to ask: "Is the sequence of events shown on the curve of community centeredness versus time in Figure 29 compatible with theory?" This is an important question to ask because of the small size of the current study, and our limited data sample. Thus, if the answer were to be that it is not compatible with accepted theories of human behavior, then there would be serious questions regarding its likely validity. To assess this issue, we turn to "Mazlow's Hierarchy of Needs."

Mazlow's hierarchy of needs describes a series of human needs that can be thought of as steps (Mazlow, 1970). They range from biological and physical needs on the bottom, through safety and security needs, social needs, ego and esteem needs, to self-actualization at the top. The lower third of Figure 35 shows these steps, and links them by arrows to sections of the hypothetical curve of community centeredness versus time from Figure 29. It may be seen from Figure 35 that the first four points on the curve are closely linked to a student's safety and security needs. That is, for students, if being thought stupid mitigates against peer acceptance and peer acceptance is perceived as being essential to emotional safety, situations such as being "laughed at," "made fun of," or ostracized, may be fraught with personal risk. This is particularly true for adolescents because of their characteristic necessity of measuring themselves against peers. The fact that within a CCS classroom students are able to satisfy their safety and security needs allows them to move rapidly to the next step on Mazlow's hierarchy.

[6] For example: **Davidian –** " ... she's secretary of the Senior Class, she's an elected officer of the Senior Class, she's in the Honor society, she's an elected officer of the Honor Society, she's a Cheerleader, she's tall, blonde, gorgeous, ... um, has boyfriends galore, ... girlfriends galore, um, does very well in all her classes so in my opinion if anybody should be self-secure it should be her, .. *(but still she said)* ... "*... you don't want to ask a question because you feel stupid,* .""

Figure 35. Links with Mazlow & Self-Worth Theories

The next step on Mazlow's hierarchy of needs is social needs. This step is shown in Figure 35 linked by an arrow to the next five points on the same curve from Figure 29. Again it is clear that there is an obvious link between Mazlow's social needs and this next set of points on the curve.

It begins with class discussion, where reasons for actions taken come into the open, but here, to fully explain the process, we need to digress a little and talk about learning and its links with motivation. As von Glasersfeld (1998) remarks, "If, we repeatedly tell children that their solutions to problems are wrong, we should not be surprised that their enthusiasm ... dries up. If instead, we ask children, 'How did you go about getting this answer?' we discover that in many cases they are capable of seeing for themselves that something did go wrong." Or, as Shulman (2000) puts it, "The only way we as teachers know whether our students understand something is by getting them to write or talk about it. As long as it remains inside their heads, we cannot teach, and in fact they don't know whether they understand it either." Meier (1995) sums it up by observing, that, "When properly understood, teaching is mainly listening, whereas learning is mainly talking."

So, the major point is that the class discussion and peer interaction are not simply for their sake. They are highly relevant because they have three major outcomes, they

help learning,

show that reasons are important, and

can be common property, where sharing helps givers and receivers.

Thus, what we are trying to say is that, while the objective of the five blocked items linked to Mazlow's third step in Figure 35, is NOT to satisfy social needs, they nevertheless do this ANYWAY as a byproduct of good pedagogy. The developing peer interaction, the thought that "my ideas matter," and the developing classroom community, are likely to have profound effects on a student's view of an academic discipline and on his or her performance in that discipline.

Finally, it is likely that ego and esteem needs can also be satisfied by contributing to group and class achievement. In classes of teachers experienced with CCS technology, we have frequently observed sentiments associated with this aspect of community centeredness, such as cheering and enthusiasm and the genuine feeling that teacher and every student are on the "same side." However, as we pointed out in the previous section, limited research data is as yet available on these issues.

In concluding these comments on Mazlow's hierarchy of needs, we want to emphasize the fact of happy coincidences. That is, it was not the a priori intention of CCS technology to satisfy students emotional needs. Especially, not in such apparently perfect alignment with Mazlow's well verified and generally accepted hierarchy. However, that fact that this seems to happen is probably the cause of some of the more remarkable results that we observed. For example, several student groups stated that they were understanding the subject better, working harder, and enjoying it more. Results like this, if they are valid, have to have deep causes. The coincidences shown in Figure 35, may just be partly responsible.

Self Worth Theory

We now look at the sequence of events on the hypothetical curve (Figure 35) from the perspective of "Self-Worth Theory." Self-worth theory (Covington, 1992, 1998; Covington and Beery, 1976) is based on the hypothesis that the search for self-acceptance is the highest human priority. It represents an attempt to tie together in one principle, many human behaviors. It stems from ideas that "individuals function directly from their inner core of psychological wellness" (McCombs, 1998), and it has been

successful at explaining a wide variety of behaviors in educational environments. For example, Cross and Steadman (1996) recount that, "Self-worth models of motivation explain how students in competitive environments attempt to preserve their sense of self-worth, which is based in large part on self-perceived ability. Students who do well in the competition of the classroom feel good about themselves, whereas students who do poorly must question either their ability or their effort. And most students would rather question – and have others question – their effort than their ability. To be thought smart is a source of status and prestige to students; most would rather be thought lazy than dumb (Brown and Weiner, 1984)."

It is easy to see how the advent of an environment that makes it, "safe to try," and, ensures that a student, "won't be thought stupid," as in a CCS classroom, would remove the type of barriers to effort, described in the above example by Cross & Steadman. In fact, self-worth theory seems tailor made to explain the exact effects that we observed and reported Sections 8.1 through 8.3, because we observed an exactly analogous behavior, that in the short term preserves self-acceptance, but in the longer term is clearly self-defeating.

Self-worth theory also explains other stages on the curve in Figure 35. These are shown in the upper third of the figure, and are connected by arrows via a continuous bar. The "emotion snippets" shown above the bar are intended to convey typical student sentiments as the sense of community increases in the classroom. That is, as class discussion and peer interaction grow, students begin to feel that their input to the group and/or class as a whole are valuable ("my ideas matter," and "I helped the group"). As a result of non-confrontational competition, enthusiasm, natural rewards of effort, and demonstrable success, there comes a feeling of group satisfaction and belonging in the sense of "We did it!"[7]. The result is that students "feel good about themselves," for the *RIGHT* reasons. Namely, that they are learning as individuals, and also have participated in creating a successful community that is also helping others learn. In terms of the theory, such events lend integrity and cohesion to self-image and an authenticity to individuals.

Attribution Theory

Attribution theory presents another lens through which to view the data presented on our hypothetical curve (Figs. 29 and 35). The perspective it presents is less concerned with needs, emotions, and desires than with the perceived causes of results. The purpose of discussing attribution theory here, is to make the case that, the processes we described as leading to increased community centeredness, also are likely to aid "healthy attribution."

To explain attribution theory, we quote (again) from Cross and Steadman (1996), "Attribution theory, as its name implies, suggests that students *attribute* success or failure to one or more things – ability, effort, luck, fatigue, an easy exam, or a hard one, and the like. According to attribution theory, students' beliefs about their ability to succeed are based on their perceptions of why they have succeeded in the past. Students who attribute success to factors they feel they can depend on, such as their own ability, are likely to have more confidence in their future achievement than students who attribute success to unstable external conditions such as good luck or an easy test" (p81).

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[7] For example, see interview with Ann Davidian:

Davidian: Yes. Again, with them all working together as a group and all being involved and they feed off of each other, and you know, it's, "Wow guys look at that, we did this, we did that!"

In Figure 36 we show a sequence of three events immediately under the original graph, and linked to it by arrows to show relationships. The first stage happens when students are under "an appropriate amount of pressure" (Gerace in Abrahamson 1995) to establish positions and commit to them. This stage is linked to the first point on the original graph which is "personal privacy." As discussed before, the personal privacy lent by a CCS ensures that there is no embarrassment associated with ones response. The second stage comes when students see the results of their actions as well as those of others. The third, when they hear and express rationales behind their decisions.

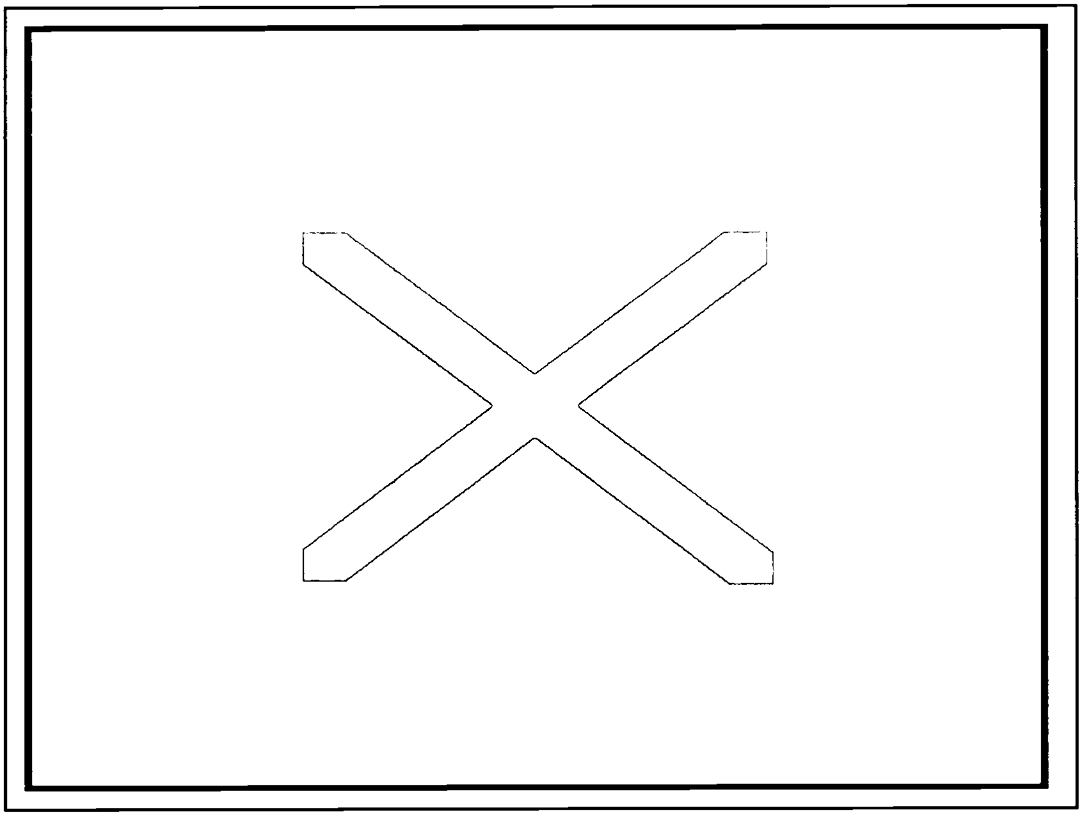

Figure 36. Links with Attribution and Self-efficacy Theories

As this sequence is repeated many, many times over a course, semester, and school year, a pattern of valid attribution is likely to become established. That is, as success is achieved in this way, it is likely to be attributed to the real actions that were its cause. This can best be described as healthy attribution.

Self-Efficacy Theory

The same processes that provide healthy attribution also provide the link to self-efficacy theory. Self-efficacy is a very powerful construct, and workers in this field believe it can explain a great deal about human behavior (Tatar 2002). The purpose of discussing self-efficacy theory here is to make the case that the processes we described as leading to increased community centeredness also are likely to result in increased self-efficacy.

Self-efficacy theory focuses on beliefs about ones ability to succeed in a particular task (Cross & Steadman, 1996; Bandura, 1997).). Thus, from self-efficacy theory, if students through their (counter-productive) actions come to believe that they are not capable of succeeding in a particular discipline, changing this belief requires changing the actions so that they can begin to see that they can be successful. For these reasons the results of processes leading to healthy attribution are shown in Figure

36, as also flowing into a belief changing process. That is, a growing confidence that, "I *can* do it!" We also think it is likely that such a transformation in a student's beliefs about their abilities may be helped by peer reinforcement within the growing classroom community.

8.7 How All the Centerednesses Overlap and Grow in CCS Classrooms

Finally we are going to make the attempt to "put it all together." In discussing underlying processes and mechanisms in the preceding sections, we have focused almost exclusively on community centeredness. Such a focus may be questioned if the connection between community centeredness and the other centerednesses is not fully appreciated. With this in mind, we wish to reinforce here, how community centeredness IS intimately connected with all the other centerednesses, and therefore with student learning.

To put it together, we return to the same figure (Figure 1) with which we began this report – the overlapping circles from *How People Learn* (HPL). This is reproduced in Figure 37 where it is shown how the different centerednesses connect with the various stages on the curve from Figure 29 (which was also shown in Figs. 35 & 36). It may be seen that the curve which depicted growth of community centeredness versus time is in fact comprised of a multi-colored hue of all the other centerednesses. That is, it begins with learner centeredness as students engage actively, continues with assessment centeredness as they receive feedback in a variety of ways, transforms to knowledge centeredness, as understanding the reasons for actions taken become important, changes again to learner centeredness as peers are able to express ideas in terms that facilitate transfer, and only finally morphs to community centeredness itself.

We must emphasize that the sequence just described is highly simplified. We use it here only to illustrate how in reality, the centerednesses can overlap. In fact, the sequence just described is likely to be only one of the many which are possible. So in practice, for example, the second segment which was labeled "assessment centeredness" is likely in some classroom situations to also become knowledge and/or learner centered, depending on the exact nature of events taking place in classrooms.

Figure 37. Overlapping Nature of the HPL Centerednesses Reflected in Our Hypothetical Curve

This may seem complicated, and it is. However, it may be easier to understand, if one realizes that the various stages on the curve are averages spread over time, and can be thought of as expressing the likelihood of these events occurring at all. Thus, for example, a complete realization of the curve from beginning covering perhaps the first eight points, may comprise as many as a dozen classroom periods spread over several weeks. So, in an individual class, the effects may range up and down the curve as the class progresses. But, a key issue that the curve is intended to show, is that the earlier in time, the less likelihood there is of events higher up the curve occurring at all, and if they do occur, they may be short lived and impact only a few students.

It is also time to answer the question of why we chose an exponential (with a tail) for our hypothetical curve. The reason was that we were intending to illustrate the likely growth of community centeredness in a CCS classroom, where the teacher was experienced with the technology and the students were not. Thus we chose to ignore issues that were related to teachers having to become familiar with the technology per se. Also, we wanted to ignore more complex issues that have to do with pedagogy. For example, it is likely from our data[8] that teachers, when they begin using a CCS, encounter circumstances that they have not experienced before. This is likely to be true no matter how long they have been teaching, or what level of distinction and expertise they have attained up to that point. The reason probably centers around the fact that they are receiving much more feedback, much more quickly, than they ever have before. Simply put, they have to learn to "listen." But, this is much more difficult than it seems because by listening we mean several things: teachers have to learn how to handle the information, interpret it, use it wisely, and how to probe for more when there are only a few clues to go on. They have to learn how to adapt their curricula, for this technology, develop new materials themselves, search and evaluate materials developed by others, and pioneer new ways.

Our test-group teachers reinforced this perception as shown by the following comments:

Kula: I think it's also forcing me to really think about the kinds of questions I'm asking them, and I usually try to think about the kinds of questions I'm asking, but Navigator is forcing me to refine and rethink, "Okay, why am I asking this question and what is I want to learn?"

Small: Some of the understanding -- I realized that, you know -- only half the class or 60% of the class was getting it. ... I have to ask myself as a teacher am I satisfied with that, ... having many times to teach to the middle of the class *[without a CCS]*. So when I was looking at those results, in my mind I'm faced with a reality that I haven't been necessarily faced with before, *because I'm learning, myself, about how I teach in a lot of ways with this, because it really expresses to me just how much connection I'm making and, "Are there better ways of making those connections?"*

Driscoll: ... when I first started using Navigator I thought it was kind of a self-contained device that would give what I needed ... with myself in a bubble of just that technology. That's where I was when I first started. ... my perception was I could - stand behind the desk, watch the answers coming in. Look at the teacher console and get what I needed and then look at the results of class and get what I need and give them what they need. Well, it didn't turn out that way. .... I had very strict rules about not talking. ... I didn't want the answers or the

[8] Unfortunately, there may be an issue associated with our data, see Appendix 4..

results skewed. ... That has come full circle and now I want them to communicate because I think through communication with other students they're going to get what they need or at least get closer to what they need.

Davidian: I think after doing things for a couple of weeks it's like an, "Oh Wow look at this!! Holy Mackerel, I can't believe I'm learning this stuff about things." That sort of happens pretty fast. Um, because you're presented with opportunities you never had before and with information you never even thought about before. So I think that happens really fast, but... if somebody came tomorrow and took my Navigator System away from me ... I don't exactly know what I would do, but I know I would do things differently. It's become part of me now and that's a gradual process. ... It's become ingrained in me and that takes time.

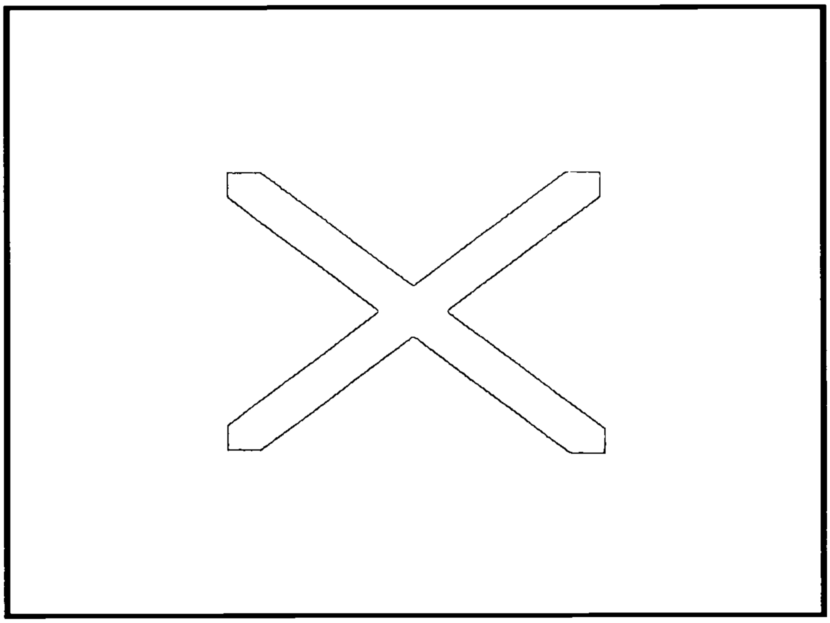

Figure 38. Staged Growth Likely for Teachers New to the Technology

Thus, in view of all this complexity that surrounds teachers new to this technology, a simple exponential is unlikely to represent the actual path of a new teacher starting off with a CCS in his or her classroom. We do feel that it is a likely path for an experienced teacher, starting with a class of students, who themselves are new to the technology. However, more work needs to be done to verify this hypothesis.

For new teachers, we speculate that the actual path may look something like that shown in Figure 38, where an initial exponential-like segment is followed by a tailing-off flatter section. In our thinking, this flatter section would be where a new teacher takes time to learn and apply some of the more difficult pedagogical constructs, whose effective use is beckoned by the technology. Where this flatter section actually occurs, and its possible duration are likely to vary substantially from one teacher to another.

NOTE: Additional information on pedagogical issues extracted from teacher interviews is contained in Appendix 6.

9. CONCLUSIONS

9.1 Conclusions from this Study

This report describes a small exploratory research project that took on a big question. That is,

"Does use of CCSs in classrooms by teachers (following a teacher training Summer Institute) tend to facilitate educational environments which are learner centered, knowledge centered, assessment centered, and communitycentered?"

It was a big question because to answer it involved not only devising, developing, and holding a teacher training institute, but also assessing its results. In particular, the theoretical model on which we chose to base our assessments is founded on deep constructs, that had never been assessed before in classrooms. Thus, we had to develop and implement the assessment methodology, virtually from scratch. Nevertheless, we feel that we were successful in all these undertakings.

We also believe that we are justified in reaching the tentative conclusion of a positive answer to the research question. That is, that use of CCSs in classrooms by teachers (following a professional development summer institute) does facilitate environments in their classrooms which are learner centered, knowledge centered, assessment centered, and community centered. This is supported by positivistic data (surveys) from student and teacher perceptions. It is also supported by extensive naturalistic inquiry of observation and interview.

As a corollary to this conclusion, we can also report that we developed instruments and processes to assess perceived changes in the HPL centerednesses in classrooms. We analyzed the data produced by these instruments to assess consistency from a statistical perspective, and found results to be consistent with the research use of these instruments, supporting the validity of the data. These instruments also showed expected growth in the HPL centerednesses over time, by comparing test-group teachers from the Summer Institute with teachers more experienced in using the technology. A further corollary is that the Summer Institute that we developed, must have been successful. That is, not only was it a very enjoyable experience for all participants (as seen by their ratings), but it was also successful in its objective to teach teachers how to use the technology effectively in their classrooms.

Finally, we set out to determine the classroom processes and mechanisms that were leading to the results we were observing. In pursuing this goal we uncovered extremely exciting, and we think portentous, links between what was occurring in classrooms, and several theories related to human motivation. These include, coping theory, Mazlow's hierarchy of needs, self-worth theory, attribution theory, and self-efficacy theory. The effect of this work, is to shed more light on how and why the centerednesses increase in CCS classrooms.

However, clearly we have just scratched the surface, and more work is needed to fully understand the promise of this exciting technology and to facilitate its possibly widespread introduction into educational environments.

9.2 Need for More Research

We are including a brief list of areas where we think more work is required:

- Do better in teaching teachers (this project represented a first tentative step in this direction, we feel there is much more to learn);
- Do better in assessing effects (again, this project represented a first tentative step in this direction, we feel there is much more to learn)
- Need more research on effects and correlation with theory – especially longitudinal studies;

- Examine ways to ease merging of this technology with existing exemplary curricula (at present, each teacher has to do this for himself or herself).

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APPENDIX 1

Annotated Program -

"Navigator Week at OSU"

The following is an annotated schedule of the week's events at the "Navigator Institute"

Navigator Week at OSU

Sunday:

7:30 Continental Breakfast

8:30 Introductions

Polling – the Hook – Doug (FHHS – Get Information)

- Ask participants to enter into Y1, Y2, Y3, and Y4
- What state are you from?
- How far did you travel?
- How many years have you taught?
- Do you know how to do a regression?

The purpose of this activity was to show the participants how the system can be used to gather information from a group of people using calculators to input data. The system is capable of accepting purely numeric answers or alphanumeric combinations.

Navigator Skills

- Log on, IDs, passwords
- Hardware basics

In this activity the logistics of how students log on to the network and technical issues of how the system is configured and operates were covered.

10:00 Break

10:30 Every Day Use

- Olympic Swimming Final – Doug

Based on data from the Summer Olympics of 2000, this activity is designed to help students in understanding and computing average rate of change. The TI-Navigator system is used as a check of background knowledge by assessing whether students have the appropriate background knowledge, in conversion of units and the calculation of speed, to attempt the main part of the activity. This formative assessment allows a teacher the possibility of adjusting the lesson by reviewing the necessary prerequisite concepts.

- Multiple Choice (FHHS Polling)
- Short Answer (FHHS Test All Questions)
- True False (FHHS True False)

Different forms in which data can be sent from calculators were reviewed in this activity. Answers can be submitted by students as a choice from a list, a string, or a true/false response.

11.45 Navigator Project

At this stage participants were given details of our research project and informed of other times through the week when aspects of the project would be presented and discussed at length.

12:00 Lunch

1:00 Content Specific (Randomness)

- Trig test – Ann (MHS Trig Test)
- Algebra I slopes – Andy (FHHS Slope)

This pair of activities demonstrated how the TI-Navigator system can be used in typical content specific lessons in the area of trigonometric identities and slopes of lines. The activities were intended to show the participants how a standard lesson would run in a TI-Navigator classroom.

2:30 Break

3:00 Student Competition – Doug (FHHS Addition of Integers, FHHS MC Game)

This activity showed how having students work in cooperative groups assigned randomly by the system can enhance student motivation and provide practice for high-stakes tests such as the SATs and APs because of the emphasis on speed.

3:30 Navigator 1.0 – Mark

In this part of the institute a representative of the Texas Instruments research team for the TI-Navigator made a presentation on the release version of the system. The presentation involved a complete description of the hardware and software involved in the TI-Navigator system.

5:00 Debrief – Frank

At this time the participants gave the team feedback on how the day had gone for them and suggestions on improvements. On the basis of this feedback the timetable for the rest of the week was redrafted.

6:30 Dinner – Holiday Inn on the Lane

Monday:

7:30 Continental Breakfast

8:30 Class Starter/Checking Homework

- MHS DATASEND - Ann
- Quiz – Doug (FHHS Test All Questions)

These activities served to show how the TI-Navigator system can be used to check homework by allowing students to send a collection of answers to the teacher computer for automatic checking and grading.

10:00 Break

10:30 Immediate Feedback
- MHS Analyze the Graph- Calculus (Student/Teacher) - Andy
- MHS Write Some Equations – Precalculus (Student/Teacher) - Andy
- Choose My Topic (Teacher) – Doug (FHHS Send Y1, FHHS Student Teacher Communicate)

One of the most important pedagogical techniques facilitate by the TI-Navigator is the possibility of immediate feedback to a student on their choices and answers. These activities were designed to exhibit this possibility in the context of content specific material in Calculus and pre-Calculus.

12:00 Lunch

1:00 AAAPolling Facilitator 2.0 – Doug

This activity introduced participants to a program which facilitates various kinds of polling such as the choice of the correct answer from a list of four or five, an entry of a true/false answer or the entry of a short response. The activity also helped participants reflect on various uses of poll data such as formative assessment or as a springboard for a class discussion.

2:00 Debrief

This time was another opportunity for participants to feedback to us about their problems, concerns or praise for what had happened thus far in the institute.

2:30 Website Investigation – Ramseyer 009

and/or

Project Activity - Arps 269/286

As part of their participation in the institute the teachers were asked to engage in a group project in which they would develop a lesson or activity to help them think about their own use of the TI-Navigator system in their classroom. At this time participants were offered the choice of working on their project or joining a session which would explore the Texas Instruments website supporting the Navigator system.

4:00 Practice with Equipment - Arps 286

Only one system was available for the institute and so it was important to find time when

participants could take the teacher's position and practice the logistics of running an activity for a class using the system. Several other opportunities were provided through the week.

6:30 Dinner – Holiday Inn on the Lane

8:00 Practice with Equipment - Arps 274

This was another practice session with the teacher console.

Tuesday:

7:30 Continental Breakfast

8:30 Data Collection – FHHS List Blaster – Doug

9:30 Damped Oscillations - FHHS List Blaster - Doug

This pair of activities showed the teachers how data generated by individual students can be gathered together via the teacher machine and then redistributed in its entirety to a whole class set of calculators. In this way each student in a class can generate a small set of observations for an experiment but the pooled data can be distributed quickly and easily so that each student has every other student's observations as well as their own.

10:30 Break

11:00 Pedagogical Implications of Prior Research and the TI-Navigator - Louis

At this time one of the projects PIs made a presentation on the theoretical framework for the research project and the current state of research into Classroom Communication Systems (CCSs). The results of prior research into such systems was presented as well as a theoretical overview of the changing nature of classroom environments promoted by CCSs.

12:00 Lunch

1:00 Investigating the Pendulum – MHS Swing Thing - Ann and Andy

This activity showed how the system could be used in a physics experiment. Data is gathered by students in their own experiments and then pooled centrally by using the TI-Navigator.

2:00 Programming (optional session) – Doug

and/or

Project Work

At this time participants could work on their projects or take part in a session which focused on programming techniques for writing activities for the system. Such activities are generally posted to the Texas Instruments website for the use of the Navigator community so the ability to write programs is not necessary for use of the system.

3:30 Debrief – Arps 274

This time is the daily opportunity for participants to feedback to us about their experiences thus far in the institute.

4:00 Practice with Equipment

Participants were again given an opportunity to see the system from the teacher's side.

6:00 Depart Hotel for Dinner at The River Club

Wednesday:

7:30 Continental Breakfast

8:30 Phases of the Moon - Kiski Moon Phase - Ann and Andy

This astronomy activity demonstrated to the participants how the system may be used, in conjunction with data, garnered from the internet to investigate the nature of the phases of the moon. This activity was a good example of how the TI-Navigator and TI-Interactive systems can work together.

10:00 Break

10:30 Assessment of TI-Navigator Implementation– Louis, Doug

This was the principal session in which participants were informed of the logistics of the research project in terms of the paper work required from them as well as the timing of and requirements for the team on-site visits required to evaluate their use of the system in their classrooms.

11:15 Projects/Reports

Most of this day was set aside to allow participants to share with one another the results of their project. Small groups made brief presentations on their emerging ideas for the possible use of the system with their own classes.

12:00 Lunch

1:00 Projects/Reports

This session was a continuation of the project presentations.

3:15 Debrief

This time was another opportunity for participants to feedback to us about their problems, concerns or praise for what had happened thus far in the institute.

4:00 Practice with Equipment – Arps 286

This was the final practice session with the equipment.

6:00 Dinner – Holiday Inn on the Lane

Thursday:

7:30 Continental Breakfast

8:30 Participatory Simulations Project– Andre Mack

This activity allowed the teachers to experience a participatory simulation whereby each person controls part of what is happening to a system visible to all on screen. Among the simulations presented were the propagation of a disease through a population and the collective control of a traffic system.

10:00 Break

10:30 Wrap up and discussion

This was the final debriefing session of the institute.

11:30 Final Debriefing and Evaluation

During this time the formal questionnaire allowing participants to evaluate the institute was distributed and filled out.

APPENDIX 2
Research Instruments

a) Initial Teacher Questionnaire
b) Pre-visit Questionnaire
c) Student Survey
d) Teacher Survey
e) Classroom Observation
f) Student Focus-Group Interviews
g) Teacher Interview
h) Final Teacher Questionnaire

TI-Navigator Research Project

Teacher Visit Preparatory Sheet

1. Using a scale of 1 to 6, with 1 being highest and 6 being lowest, rank the following pedagogical techniques, discussed in August, 2001 institute, in terms of (a) frequency of use, (b) total time of use, and (c) effectiveness, in your classroom

(a) **Frequency of use** **Rank**

Competitions/Games	_____
Data Collection	_____
Immediate Feedback	_____
Polling	_____
Randomness	_____
Simulations	_____

(b) **Total time of use** **Rank**

Competitions/Games	_____
Data Collection	_____
Immediate Feedback	_____
Polling	_____
Randomness	_____
Simulations	_____

(c) **Effectiveness** **Rank**

Competitions/Games	_____
Data Collection	_____
Immediate Feedback	_____
Polling	_____
Randomness	_____
Simulations	_____

2. In a typical lesson where you are using the TI-Navigator what percentage of time is spent using the system?

3. In a typical week in your classroom what percentage of periods is the TI-Navigator in use?

4. Before you used TI-Navigator how did you find out what students were weak at?

5. Is the TI-Navigator useful in establishing students' prerequisite skills needed to master new concepts? Explain.

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6. List three things you like about using the TI-Navigator.

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7. List three things you dislike about using the TI-Navigator.

TI-Navigator Research Project
Student Survey

Student Name: ______________________________ Date:

Teacher's Name:________________________ Class Period:____________________

For each of the following statements indicate whether you Strongly Disagree (SD), Disagree (D), Neither agree nor disagree (N), Agree (A), or Strongly Agree (SA) by circling the appropriate choice to the right of the statement.

1	Using the TI-Navigator does not help improve my understanding	SD	D	N	A	SA
2	Class dynamics are not affected by the use of the TI-Navigator	SD	D	N	A	SA
3	The teacher knows just as much about my understanding without the TI-Navigator as with it	SD	D	N	A	SA
4	There is a greater sense of community in a TI-Navigator class than in other classes	SD	D	N	A	SA
5	The TI-Navigator helps the teacher tell if I understand a concept	SD	D	N	A	SA
6	I am more actively engaged in a TI-Navigator class than in others	SD	D	N	A	SA
7	The TI-Navigator makes no difference to my effort in answering questions	SD	D	N	A	SA
8	I find no advantage in using the TI-Navigator to help me build on my knowledge	SD	D	N	A	SA
9	Some TI-Navigator questions make me try really hard to answer them	SD	D	N	A	SA
10	I am equally on task in TI-Navigator classes and other classes	SD	D	N	A	SA
11	Using the TI-Navigator does not help in letting me know where I stand on a question	SD	D	N	A	SA
12	Using the TI-Navigator I can quickly tell whether or not I am right or wrong	SD	D	N	A	SA
13	Doing activities with the TI-Navigator in class helps me get a better understanding of concepts	SD	D	N	A	SA
14	Class interactions resulting from using the TI-Navigator help my learning	SD	D	N	A	SA
15	Doing activities in class with the TI-Navigator helps me relate new material to things I already know	SD	D	N	A	SA
16	Using the TI-Navigator does not improve the sense of community in classes	SD	D	N	A	SA

TI-Navigator Research Project

Teacher Survey

Name: ______________________________ Date: ______________________________

For each of the following statements indicate whether you Strongly Disagree (SD), Disagree (D), Neither agree nor disagree (N), Agree (A), or Strongly Agree (SA) by circling the appropriate choice to the right of the statement.

1	Using the TI-Navigator does not help improve student understanding	SD	D	N	A	SA
2	Class dynamics are not affected by the use of the TI-Navigator	SD	D	N	A	SA
3	I know just as much about student understanding without the TI-Navigator as with it	SD	D	N	A	SA
4	There is a greater sense of community in a TI-Navigator class than in other classes	SD	D	N	A	SA
5	The TI-Navigator helps me tell if the students understand a concept	SD	D	N	A	SA
6	Students are more actively engaged in a TI-Navigator class than in others	SD	D	N	A	SA
7	The TI-Navigator makes no difference with regard to students' effort in answering questions	SD	D	N	A	SA
8	There is no advantage in using the TI-Navigator to help students build on their previous knowledge	SD	D	N	A	SA
9	Some TI-Navigator questions make students try really hard to answer them	SD	D	N	A	SA
10	Students are equally on task in TI-Navigator classes and other classes	SD	D	N	A	SA
11	Using the TI-Navigator does not help in letting students know where they stand on a question	SD	D	N	A	SA
12	Using the TI-Navigator students can quickly tell whether or not they are right or wrong	SD	D	N	A	SA
13	Doing activities with the TI-Navigator in class helps students get a better understanding of concepts	SD	D	N	A	SA
14	Class interactions resulting from using the TI-Navigator help student learning	SD	D	N	A	SA
15	Doing activities in class with the TI-Navigator helps students relate new material to things they already know	SD	D	N	A	SA
16	Using the TI-Navigator does not improve the sense of community in classes	SD	D	N	A	SA

TI-Navigator Research Project

Student Focus Group Protocol

The student focus group will take place after the classroom observation. Its principal purpose is to elicit amplification on responses to the survey. A typical question would be: One of the survey questions asked you respond to the statement "The TI-Navigator helps me tell if the students understand a concept." Most students said that they Strongly Agreed (SA). Why did you think they responded in this way?

Reflecting on the classroom observation other possible questions would be:

How typical was the use of the TI-Navigator in your lesson today?

What do you think was the purpose of the use of the TI-Navigator today?

For what other purposes has the TI-Navigator been used?

Do you typically get homework which will involve use of the TI-Navigator?

Are there technical difficulties in using the system?

If so, describe the effect on your learning.

TI-Navigator Research Project

Teacher Interview Protocol

The teacher interview will take place after the classroom observation. Its principal purpose is to elicit amplification on responses to the survey. A typical question would be: One of the survey questions asked you respond to the statement "The TI-Navigator helps me tell if the students understand a concept." You responded that you Disagree (D). Why did you respond in this way?

Reflecting on the classroom observation other possible questions would be:

How typical was your use of the TI-Navigator in your lesson today?

What was the purpose of your use of the TI-Navigator today?

For what other purposes have you used the TI-Navigator?

Do you typically assign homework which will involve use of the TI-Navigator?

Do you have technical difficulties in using the system?

If so, describe the effect on your teaching and student learning.

TI-Navigator Research Project
Final Teacher Questionnaire

Name

____

____

1. In the past year how often would you say you have integrated each of the following into your classroom teaching?

	Frequently	Sometimes	Never
Non-graphing Calculators	[ ]	[ ]	[ ]
Graphing Calculators	[ ]	[ ]	[ ]
Personal Computers	[ ]	[ ]	[ ]
Technology or information from the World Wide Web	[ ]	[ ]	[ ]
Classroom Communication Systems (e.g. TI-Navigator, Classtalk)	[ ]	[ ]	[ ]

2. Describe how you have used graphing calculators in your class in the last year.

____

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____

3. Describe three impacts of using the TI-Navigator on your classroom.

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4. Describe the impact of the August, 2001 institute on your use of the TI-Navigator.

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5. What teaching strategies do you typically use in you classroom?

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6. Rank these strategies in order of how much time you spend using them.

7. List reasons for asking questions in a classroom setting.

8. Comment on any differences in your classroom that you feel were influenced by use of the TI-Navigator.

9. What was the most unexpected impact of teaching with the TI-Navigator on your classroom?

APPENDIX 3

Informal Summary of Topics from HPL

(with notes on issues pertaining to this research)

How People Learn: Brain, Mind, Experience, and School

John D. Bransford, Ann L. Brown, and Rodney R. Cocking, Editors; Committee on Developments in the Science of Learning, National Research Council
346 pages, 6 x 9, 1999.

The hardcover edition of "How People Learn" is no longer available. It has been reprinted in paperback. The new edition has been expanded to include practical information to show how the theories and insights from the original book can translate into actions and practise, making a real connection between classroom activities and learning behavior.

When do infants begin to learn? How do experts learn and how is this different from non-experts? What can teachers and schools do--with curricula, classroom settings, and teaching methods--to help children learn most effectively?

This book offers exciting new research about the mind and the brain that provides answers to these and other questions. New evidence from many branches of science has significantly added to our understanding of what it means to know, from the neural processes that occur during learning to the influence of culture on what people see and absorb.

How People Learn examines these findings and their implications for what we teach, how we teach it, and how we assess what our children learn. The book uses exemplary teaching to illustrate how approaches based on what we now know result in in-depth learning. This new knowledge calls into question concepts and practices firmly entrenched in our current education system. Topics include:

- How learning actually changes the physical structure of the brain.
- How existing knowledge affects what people notice and how they learn.
- What the thought processes of experts tell us about how to teach.
- The amazing learning potential of infants.
- The relationship of classroom learning and everyday settings of community and workplace.
- Learning needs and opportunities for teachers.
- A realistic look at the role of technology in education.

If education is to help students make sense of their surroundings and ready them for the challenges of the technology-driven, internationally competitive world, then it must be based on what we know about learning from science. In that light, this book will be of significant professional interest to teachers, education policymakers and administrators, and curriculum developers.

LEARNER-CENTERED ENVIRONMENTS
"Learner centered" refers to environments that pay careful attention to the knowledge, skills, attitudes, and beliefs that learners bring to the educational setting.

This term includes teaching practices that
- build on the conceptual and cultural knowledge that students bring with them to the classroom by
    - constructing a bridge between the subject matter and the student
    - helping students make connections between their previous knowledge and their current academic tasks
    - identifying students' knowledge, interests, and passions
    - incorporating students' home and community cultural practices and language use
    - connecting everyday talk with school talk
- fit the concept of "diagnostic teaching" by
    - attempting to discover what students think in relation to the problems on hand
    - challenging and discussing students' misconceptions sensitively
    - giving students situations (critical tasks) to go on thinking about which will enable them to readjust their ideas
    - prompting students to explain and develop their knowledge structures by asking them to make predictions about various situations and explain their reasoning for their predictions
    - discussing conflicting viewpoints
- have been called "culturally responsive," "culturally appropriate," "culturally compatible," and "culturally relevant"

<u>Researchers are interested in what extent/degree teachers:</u>
*diagnose students' existing conceptions at hand
*modify how to teach a topic based on diagnosis
*adjust what will be taught in what order
*help students see how new concept relate to previously-learned concepts
*utilize anonymity aspect of Navigator
*utilize polling and histograms from Navigator to
- diagnose current student understanding
- use current understanding as a springboard for discussion

*encourage active engagement/participation
*expect students to commit to a thought in response to questions and problems in class
*expect students to stay on task

*follow up on why/how students respond as they do

KNOWLEDGE-CENTERED ENVIRONMENTS

Knowledge-centered environments take seriously the need to help students become knowledgeable by learning in ways that lead to understanding and subsequent transfer. In mathematics, NCTM's 2000 *Principles and Standards for School Mathematics* helps define the knowledge and competencies that students need to acquire.

Teaching practices in knowledge-centered environments

- take seriously the need to help students become knowledgeable by learning in ways that lead to understanding
- focus on the kinds of information and activities that help students develop an understanding by
    - critically examining existing curricula
    - considering depth vs. breadth of content covered
- include an emphasis on sense-making—on helping students become metacognitive by expecting new information to make sense and asking for clarification when it doesn't
- fit the concept of "progressive formalization" by
    - beginning with informal ideas that students bring to school and gradually help them see how these ideas can be transformed and formalized
    - moving from students' own words to standard conventional language and notation after they have had sufficient experience with underlying concepts
    - questioning what is developmentally appropriate to teach at various ages
- foster an integrated understanding or overall picture of the discipline (i.e., mathematics) instead of skills in isolated pieces by
    - structuring activities so that students are able to explore, explain, extend, and evaluate their progress
    - striking the appropriate balance between activities designed to promote understanding and those designed to promote the automaticity of skills necessary to function effectively

<u>Researchers are interested in what extent/degree teachers:</u>

*emphasize sense-making and understanding

*structure activities so that students are able to explore, explain, extend, and evaluate their progress

*strike an appropriate balance between activities designed to promote understanding and those designed to promote the automaticity of skills necessary to function effectively

*utilize immediate feedback aspect of Navigator to

- get students to diagnose their own errors and misconceptions after committing to an initial response to a question or problem
- remedy misconceptions
- explore phenomena and follow up with (mathematics) content knowledge

ASSESSMENT-CENTERED ENVIRONMENTS

The key principles of assessment are that they should provide opportunities for feedback and revision and that what is assessed must be congruent with one's learning goals.

Teaching practices in assessment-centered environments
- utilize both formative and summative assessment
    - formative—sources of feedback to improve teaching and learning (ex: informal comments on work in progress)
    - summative—measures of what students have learned at the end of some set of learning activities (ex: unit exams)
- focus on understanding, not just memory for procedures or facts
- provide continuous, yet not intrusive, feedback as part of instruction
- monitor both group work and individual performances
- help students build skills of self-assessment and peer-assessment
- provide students with opportunities to use assessments to revise their thinking
- help teachers rethink their teaching practices

<u>Researchers are interested in what extent/degree teachers:</u>
*(all of the above bullets)
*utilize polling and histograms from Navigator to assess student understanding

COMMUNITY-CENTERED ENVIRONMENTS

"Community centered" refers to several aspects of community, including the classroom as a community, the school as a community, and the degree to which students, teachers, and administrators feel connected to the larger community of homes, businesses, states, the nation, and even the world.

In community-centered classrooms and schools, learning is enhanced by social norms that
- value the search for understanding
- value high standards for learning

- allow students and teachers the freedom to make mistakes in order to learn
- do not hinder students' willingness to ask questions when they do not understand the material
- explore new questions or hypotheses
- convey expectations for school success for all students
- are sensitive to modes of participation and levels of competition that may be unfamiliar to students
- connects what is learned in school to out-of-school learning and vice versa

<u>Researchers are interested in what extent/degree teachers:</u>
*place importance on the search for understanding (as opposed to just getting a correct answer)
*ask "why" -- ask students to justify their responses
*allow themselves and their students to make mistakes without embarrassment
*promote shared understanding through a cooperative environment
*incorporate aspects which had been observed in prior CCS classrooms (Abrahamson, unpublished) for building a sense of community

- class discussion
- peer interaction
- reasons for actions taken
- knowledge of class positions
- same side as teacher
- lack of embarrassment
- pride in class achievement
- know others have same difficulties
- cheering and enthusiasm
- non-confrontational competition

APPENDIX 4
- Description of Problems with Two Items on Student & Teacher Surveys

Description of Problems with Two Items on Student & Teacher Surveys

This Appendix contains a discussion of possible dual interpretations of two items on the student and teacher surveys. These two items were Statement L^{-2} (survey stmt. #10) and Statement A^{-2} (survey stmt. #3). In the first case (L^{-2}), we are confident in reporting that the statement was ambiguous and could logically be interpreted in two different and opposite ways. In the second case (A^{-2}), application of strict logic does not yield such ambiguity, however, there is some question about whether some misapplication of logic occurred or not. Each of these cases will be dealt with separately below.

1.) Description of Problems with Statement L^{-2} on Student and Teacher Surveys

This statement appeared on the student survey in the following form:

L^{-2} (10) I am equally on task in TI-Navigator SD D N A SA
classes and other classes

The essence of the dual interpretation centered around what it might mean to agree or disagree with this statement. Suppose for example that a student were of the opinion that he or she was "more on task" in TI-Navigator classes than in other classes. Then, such a student could disagree with the statement on the grounds that she was not "equally on task," because she was in fact "more on task." Also, if she felt that she was "*much* more on task" in TI-Navigator classes, then she could easily disagree strongly with the statement.

However, another student starting off with the same idea that he or she was "more on task" in TI-Navigator classes than in other classes, could think differently. He could think that he was indeed "at least as much on task" in TI-Navigator classes as in other classes. Therefore, he would agree with the statement. If he was *really* convinced of the fact that Navigator helped him to focus on the activities, then he could easily agree strongly with the proposition.

This ambiguity surfaced clearly in the words of the students. We found in our student focus group interviews, that students who in fact believed the same thing chose opposite positions on the survey. Because of this discrepancy, the results presented in Sections 5 and 6 of the report, omitted *all* student data from this survey item. That is, all results presented in these sections for the "active engagement" component of learner centeredness, were based solely on responses to survey item (L^2), and appropriately normalized to reflect this fact.

Although, this process was not ideal and was not what we would have wished, we do feel that the results for this learner centeredness component are reliable. This item on which we based our data was:

L^2 (6) I am more actively engaged in a TI-Navigator SD D N A SA
class than in others

This is a simple, clear, statement with no ambiguity in its interpretation.

We should add that exactly the same problem was encountered with dual and opposite interpretations by the teachers on the equivalent item on the teacher survey. Thus, we followed exactly the same process in analyzing and reporting teacher survey data, as described above for the student surveys.

2.) Description of Possible Problems with Statement A^{-2} on Student Surveys

The student survey item in the assessment centeredness component of feedback to the teacher, which we feel might have led to ambiguous interpretation, was:

A^{-2} (3)	The teacher knows just as much about my understanding without the TI-Navigator as with it	SD	D	N	A	SA

In contrast to the prior case described in this Appendix, the reason for questioning this item did not come from student focus group interviews. In interviews, students seemed generally clear on its meaning and we failed to uncover any dual interpretations. However, there *are* two main reasons why we have placed a question-mark under this data:

1. Because it is of similar linguistic structure to L^{-2}, and thus should be critically examined; and,
2. The results from this item showed a different pattern (see Figure 23), to data for other student survey items.

There are however, possible reasonable explanations for the differences in data pattern. We have speculated in the report, that this difference in pattern, may be due to teachers "having to learn to listen." On balance, our tentative opinion is that the data are valid. Thus, we kept it in, and did not omit data for this student survey item in the report. We feel that this procedure can also be justified on purely linguistic grounds, since the words "just as much" in the context of this item do not have the same meaning as "equally" in the L^{-2} case.

All this discussion might seem like a nit-picking minor point, but it has potential significant importance, that is enhanced by our tentative interpretation of the data. Namely, that teachers new to the technology "have to learn to listen" and that it takes time to learn and apply some of the more difficult pedagogical constructs, whose effective use is beckoned by the technology. And, that the students are telling us this. However, we caution that this interpretation requires more research to verify.

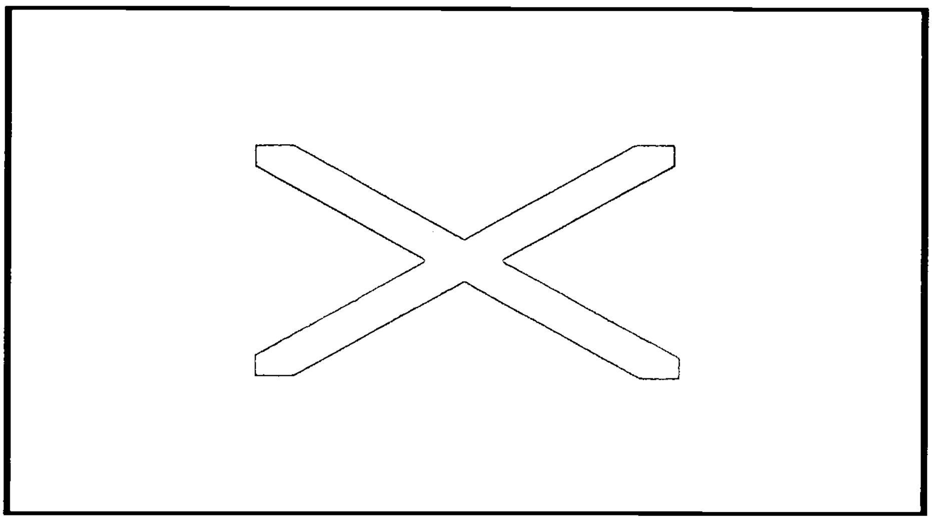
Finally, we should note that there was no evidence of dual interpretation in data for this item in data from the teacher surveys. However, the teacher data showed no similar pattern discrepancy as the student data. This result could also support our tentative conclusion. Namely, that the data for this item is valid, and that the teachers may begin by thinking they have no problem listening, and that it takes longer with the technology to appreciate this subtlety.

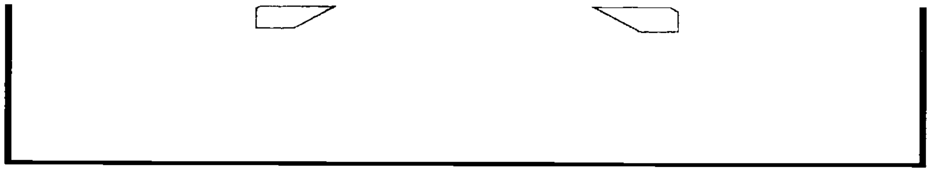
APPENDIX 5
Means & Standard Deviations of Student Survey Data for Individual Teachers

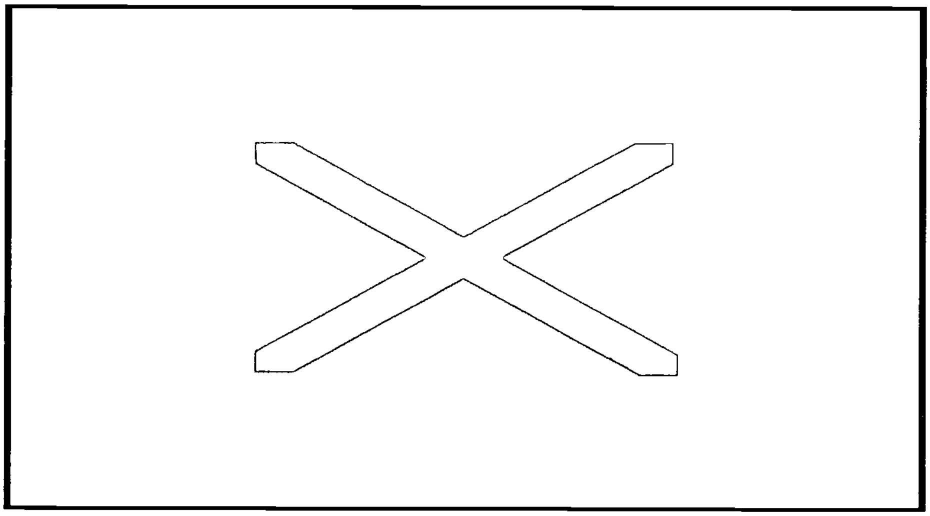
Means & Standard Deviations of Student Survey Data for Individual Teachers

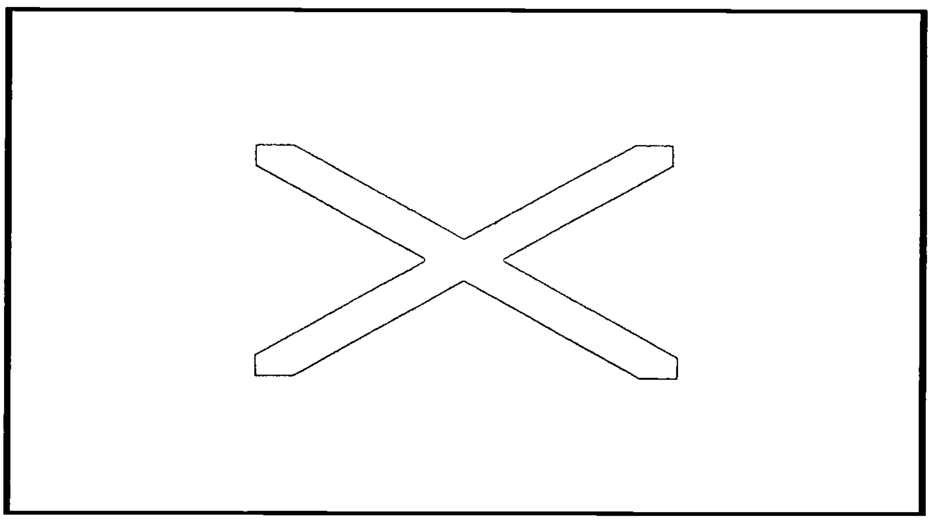
The data in this Appendix is included to show the variability of the student survey data about the means listed in Tables 5 and 7, and plotted in Figures 23 and 24 (Section 7). Each plot below shows the mean and standard deviation for each item in the student survey, averaged over all classes taught using the TI-Navigator, by a single teacher. In the plots below a value of "1" is equivalent to "disagree strongly," "2" to "disagree, "3" to "neutral," "4" to "agree," and "5" to "agree strongly."

It may be seen that student perceptions of the experiences offered by each teacher, using the TI-Navigator) are clearly different. However, data for each teacher generally follows the same sinusoidal-like variation about a mean of "3," with the amplitude varying from one teacher to another. This generally follows a trend that the greater the usage (and the fewer the technical problems), the greater the amplitude. In this respect, the difference between the tes-group teachers and the experienced teachers is particularly noticable









APPENDIX 6
Additional Discussion of Pedagogical Issues from Teacher Interviews

Additional Discussion of Pedagogical Issues from Teacher Interviews

The purpose of this appendix is to describe additional perspectives on pedagogical issues related to using CCSs in classrooms. This information was contained in our teacher interviews, and we felt that it was important to include it in this report. Specifically, we have divided it into four categories:

1. Reasons for using a CCS-based activity;
2. What you can do as a teacher when you start getting information from this activity on student work;
3. Comments on 'running' an activity; and,
4. Some ideas on frequency of use.

1.) Reasons for using a CCS-based activity;

a) To correct conceptual problems "while their minds are on it"

Many teachers spoke about the ability that TI-Navigator gave them to address issues of understanding as soon as they became evident. Doing this may have involved teacher explanation, class discussion, small group work, or more activities. Jim Small articulates the benefits:

Small: … as long as you have their mind on the topic knowing whether they're right or wrong and correcting it while their mind is still focused, is much more efficient than the delay of days that it takes sometimes to get papers back to them because at that point it's old news and unless they're really focused on the topic then they're, … they don't go back and read my comments, they don't, … they make 72 on a test they're not going back and rechecking their answers, because they've already done that! They'll probably never revisit that again. So my ability to correct their answers or to see the trends of the class while their mind is still on the topic is much more efficient, and so I think their ability to respond to their own answers can be greatly improved through something like this.

b) For creating and visualizing experimental data

We know that there were many examples of this type of activity that teachers used, but at this point they are undocumented. However, one example was discussed by Diane Hirsch in her interview. It relates to statistics and creating a larger data sample by using the network to collect and aggregate all experimental data from the class. Specifically, students were required to enter the sum for each roll of two dice, and repeat for fifty rolls.

Hirsch: … rolling two dice and "What are all your possible outcomes?" and, they never really quite got it, until they started seeing the curve, the histogram, and then we had a huge discussion on why you get more, why is easier to roll this roll than it is to roll that roll and I think the fact that we could look at the graph directly from the rolls that the kids had put into their calculators and everybody's responses.

Int: You did the sum of two …??

Hirsch: They're doing the sum of the two dice and looking at that probability. It really did, it really did help them visualize the probability a lot more and I've done probability activities where we've drawn it out and all that but I think because everybody did. I think we had everybody do about fifty rolls, put them in the list, and we did it off of a program where we made the program roll the dice. It created then on the list and then everybody sent that list in so we had twenty-five students times fifty rolls so we kept building it. We had one person send

it in and see what it looked like, two or three more people sent it in and we'd see what it looked like.

Int: Oh right!

Hirsch: So we built it throughout the thing ...

Int: Instead of? You didn't just get it ...

Hirsch: We didn't get it all at one time.

Int: That's nice!

Hirsch: You know, we started with one and then we said "Ok, have a couple of people from these groups send them in." And then at the end we'd have everybody's so we kind of watched it build.

c) As a 'launching-pad' to a new topic

At the time when we conducted the interviews, teachers were also beginning to experiment with innovative pedagogical reasons for Navigator activities. For example, Jim Small discusses how he taught two classes differently. In the first he introduced a topic by asking two questions on material he had not yet covered, and was pleasantly surprised by the result:

Small: ... two of the questions we had not even mentioned. I wanted to see how they responded and then use that as a launching pad to go into that topic. And then, ... because the students missed the question, and that gave them a buy-in, ... to wanting to know why? "What is this critical angle?" "What is this thing,?" Whereas later, *[when, using the same questions for assessment after the exposition of the material in a different class]* it was just part of it in the second class, it was part of continuing knowledge and it just blended in with everything else and so I was only getting about a 60%, you know, positive answer. Whereas, I imagine in that first block if I had gone back over and tested the question again I would have gotten you know 80 or 90% because they would have understood -- anyway, I'm using it as a tool for me, ... to see which one is a better teaching technique.

d) Generating classroom discourse

In creating class discussion, even in the context of homework or tests, teachers found students responded well to use of Navigator:

Verde: Iuse the polling the most. Because, that generates the most classroom discourse. And another one I use them for "Y-equals." Where they just send in words or answers and then if you have vocabulary tests, poetry on paper it's more novel and they really thought they were pretty neat to do that and they wanted to participate and ... it was a good positive thing.

e) Writing equations

Converting words & situations into mathematics is always challenging for students. The excerpt below shows how one teacher used Navigator to give students practice:

Davidian: There would be lessons where I would use it *[TI-Navigator]* every day. When we're first writing equations, ... and that's a great way of checking. You know Tom has a program for writing equations, so I would use it more *["Tom" was one of Davidian's students who became skilled at writing programs for TI-Navigator]*. ... You know kids have a hard time reading a word problem and writing the equation. So once the kids can write an equation given a set of facts then my focus will turn to reading the word problems, writing the equation from the information in the word problem.

Doing this in a synchronous fashion with the whole class, also gave opportunities for quick feedback, and modeling of the thought processes necessary for this type of exercise.

f) Competitions & Games

Some teachers reported finding that their students were very motivated by competitions and games. One teacher used generic activities to create game situations in her classroom:

Verde: I use the competitions and games also. I haven't found any on the Navigator that I can use so I have to use like "the sending information one" and then I makeup a game that they can use for like "Jeopardy." They keep saying, "I want to play Jeopardy!" "Let's play Jeopardy!" and so we use the Navigator and then I send in their, ... they pick their answers using the "sending information."

There is much scope for improvement and diversity in this category of activities, because clearly Navigator affords rich opportunities for a multitude of participatory class-wide learning games. Another example follows:

Int: Did it feel almost like they were all playing a game when they were doing the gridlock?

Ann: Oh yes, it is a game to them. It's completely a game! A, disease is a game to them also. They call it the "Disease Game" *[speaking of Willenski & Stroup's (2000) simulation of disease transmission]*. After my pre-cal kids, ... one day after I had done the disease simulation with my pre-cal kids, ... there was to an assembly or something where a bunch of them weren't in class, only 3 or 4 in class so I couldn't present any new material so I asked them if they had any questions or anything they wanted to go over, or if not, I was going to give them basically a study hall, and one of the kids had asked if they could play the "Disease Game." So I set up the disease simulation and they played that for about 15 minutes. Um, so they all know what that curve looks like. They call it the "S" curve. *(Laughs)*

g) Building a derivative function

There seems to be almost unlimited variation on the theme of assigning an activity that encourages students to think through issues, establish positions, and commit to positions. This is frequently followed by class-wide or small group discussion. It might be thought that such activities would become stereotyped and boring, but the following example illustrates how this does not seem to be the case, and that in fact, the reverse is true:

Davidian: Also, the nice thing with Navigator which we haven't discussed, is not only seeing answers, but when the kids are using a program that involves a graph they can visually learn. Mike wrote a program where I can input a function *["Mike" was another of Davidian's students who became skilled at writing programs for TI-Navigator]* and then the kids will look at the function and each of them will input three points, ... three points that would lie on the graph of the derivative of the function that they're visualizing and then we collect all the points and then we look at them. We discuss what points are right, what points are wrong, why they're right, why they're wrong, and then we redo it. Each time it takes normally, it takes usually about three tries, but after the third try it's the most amazing thing. It's almost perfectly correct, which is interesting because the kids are sort of scaling it on their own based on what they see looking on a screen, and one kid mentioned it, and the other kids really jumped on that, that visually seeing things is a tremendous help to them.

2.) "What to do when you see the results!"

This is an issue which is at least as important as the content of the activities themselves. Yet, it is also one that is almost strange, new, and oddly exciting to teachers. They can "Ham it up!" in ways that create humor and excitement in the classroom. They can be discrete sensitive and gentle. Or, they can be probing and play the court prosecutor, or the encouraging team "coach." Some of these options can be seen by reading between the lines of the following examples.

a) "If we were a democracy!!!"

Debbie Kula noticed that the first instinct of her class was to assume that the majority was always right. Her way of dealing with this assumption is described below:

Kula: There weren't any instances today where the majority really picked the incorrect answer, but I have had that happen and its been a marvelous discussion. So, usually when I saw that happen, in the past I would say, "Well if we were a democracy we would go with the biggest vote getter!!!!!" and, I've said that several times and they're very cautious now, ... because I say it whether they've answered correctly or incorrectly so now, so now they're trying to figure out .....

Int: *laughs*

Kula: ......if, ... I'm leading them on!!!

Int: Do you think that gets them interested when they find that a lot of them are wrong?

Kula: They want to know why. I think, they care a little bit more about it. Um, they don't seem quite as ready to just write it off.

b) I'd come over real casually & say, "Maybe you need some help!"

The question arises with teachers new to the technology, of how they should deal with a situation when they discover that only a small number of students are having difficulties. Diane Hirsch describes her solution:

Hirsch: You know I've had a couple of kids where they've been doing the ... *[activity]*... and I've looked up and noticed that they're getting quite a few of them wrong and I just had a discussion with them, "Why would you be choosing that one?" and "What's going on?" and maybe try to point them in the right direction if I notice what's happening wrong every time.

...

Int: So how did they react when you came down and said, "I saw on the console you're getting them wrong."

Hirsch: I just came over and just kind of real casually and said, "maybe you need some help. Let's talk about a question." ... never really discussed that it was the fact that I was looking at the Navigator that I knew that !!

Int: But they were Ok about ...?

Hirsch: Yeah!

c) "That's a pretty cool thing!"

The following examples from Ann Davidian, should help to give the reader give some idea of the opportunities given to teachers by the increased student involvement and attention facilitated by CCS technology:

Davidian: It's not just one kid saying, "Well I think the derivative would look like this!" and everybody sitting idly by. They've all done something. ... *[or]* ... When a histogram goes up, they've all contributed to that. ... *[or]* ... When there's a class score they've all contributed to that. ... So, they are all directly involved so they all are pretty active. You can see just by looking at them. Every eye is on that screen. In fact when we were doing gridlock yesterday, one of the kids said, "Oh my God, look at us, we're all nerds sitting there our eyes glued to the television set!" ... And that's a pretty cool thing!!

When students are engaged in this fashion, then "teachable moments" occur naturally. Our classroom observations over the years (Abrahamson, unpublished) have shown us that teachers relish such opportunities, and cite them as experiences that gave them great satisfaction. Because, from what we have seen, all teachers love to teach well!

3.) Ways to Run Activities

Much of the original work with CCSs (Dufresne et al (1996), Mazur 1997), Abrahamson (1998, 1999, 2000) was performed in large physics lecture-halls at universities. Because of this type of environment, the usage models tended to be "synchronous." That is, all students in the class tended to be working on the same activity at the same time. Also, the activity itself was usually of a "compact" nature, often consisting of a single multiple choice question.

This usage model is only one that we found to exist in smaller high school and middle school classrooms. There were also many variants of asynchronous activity where individual students or groups would be engaged in completely different activities. For example, the case described in the previous section (2(b)) describes a teacher conducting an activity that consisted of several individual math problems, that students could proceed through at their own pace. Another totally asynchronous example is a Navigator-directed activity (i.e. a "lab") that consumes an entire class period:

Davidian: There are certain labs that are full period labs that are Navigator directed. The music lab that Tom wrote *["Tom" was one of Davidian's students who became skilled at writing programs for TI-Navigator]*; there's a pendulum lab that Tom wrote where the kids get their instructions and the program, and the directions, and the quiz, etc.. etc., all through Navigator, so that's a full period.

It is our opinion that such extended activities will become more common as usage of the technology grows, and programs can be shared. In the case described above, Davidian was quick to take advantage of the fact that two of her students were interested in programming, and she enlisted their aid for developing several innovative activities.

Other comments on ways to run activities related to the importance of keeping options open ended, especially in multiple-choice questions. Davidian always adds the option, "I haven't got a clue!" and Driscoll adds two extra options:

Driscoll: ... it's very important for me to have two other options there in the multiple choice and in my informal classes that's the way it goes. The last two options are simply this: "I don't know!" - and also "The Answer I've found isn't present!" . More likely would be presented, "Answer not here!" So it gives me useful information, ... "I didn't know and I'm being honest about that, and I got an answer but the answer wasn't presented in the choices that you gave me."

4.) Frequency of Use

We tend to believe that the issue of frequency of use is an inappropriate question for teachers new to the technology. However, one of the teachers with longer experience provided this comment:

Int: In what percentage of your classes do you use TI Navigator? Do you use it every day in every class or

Davidian: I use it almost every day in some classes. In my AP calculus I use it every day to go over homework, ... Um, so that's always there. And then depending on what I'm doing in whatever class, I use it to go over, if I can, go over any kind of homework with the Navigator quickly I do that. In my pre-cal class we use it for the SAT II and that's multiple choice. Any time I do anything that involves anything like that I use it. Um, I have it now in my BC calculus class, and I have a PSAT prep course that just started. I use it every day in that, so those classes are automatically every day. Whenever I'm doing a CBL lab I always use it because I can get the program the kids need down to them immediately using Navigator so I always use it for that, ... I use it to check concepts sometimes, for part of the period, for writing equations and checking that, work with graphs and checking that so it really depends.

Some weeks I have it going every period every day; and some weeks it's just my class, my pre-cal or my cal that's going over homework. So it's sort of hard to tell. I kind of use it when I think it does something for the kids!

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